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OPERATIONAL ASPECTS OF VARIATIONS IN ALERTNESS

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OPERATIONAL ASPECTS OF VARIATIONS IN ALERTNESS

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SUMMARY

Variations in alertness undoubtedly affect operator performance, sometimes to a degree which significantly degrades operational effectiveness. Alertness is a biological state with behavioral, neurophysiological and biochemical elements. Related states are vigilance, attention, and arousal. This monograph summarizes the literature on these topics, as well as the influence of various environments on alertness levels, spontaneous fluctuations in alertness, and effects of such variation on operator performance. The environments under consideration include long duration flights, flights at night, monotonous tasks, solitude, mild hypoxia, and variations in thermal conditions in a flight compartment.

PART I

INTRODUCTION

The aeromedical community is frequently called upon to investigate ways of improving or maintaining the high-level performance of air crews and air traffic control personnel. We are asked to study conditions such as the type of weather encountered during a flight, ventilation, vibration, and lighting that influence crew effectiveness, and to investigate such problems as duty tours for radar operators, the number of crew members for large transports, and the division of duties for different members of a crew. The questions that arise most frequently concern the maintenance of performance. Alertness is a significant contributor to efficient performance.

Alertness......what is it? The alert animal is watchful, wide awake, vigilant, ready to act, attentive, lively, and on the lookout for attack or danger. He moves briskly, nimbly, and with celerity. We are describing a biological state, behavioral in its most obvious manifestations, clearly important for survival. The alert flier manifests all these signs and thereby enhances his own survival, but the contribution of alertness to his performance while flying is of equal and more immediate significance. The alert pilot is ready to detect signals and to execute responses----the essential aspect is readiness. The level of alertness varies. At low levels, and perhaps at very high levels, there is a potential for performance impairment. It is this potential impairment that is the focus of this monograph. Under what conditions is alertness reduced? What are the underlying factors that account for loss of alertness? How can acceptable levels of alertness be maintained? In the course of dealing with these questions, this monograph will range across several disciplines and many specific topics. The remainder of this introduction will be devoted to developing a descriptive framework for the concept of alertness.

Some theoretical formulations are necessary to assess the effect of environmental factors and working conditions on the alertness of aviation personnel. The assumption is made that all aspects of behavior do not change in the same way as a work period progresses, but that there are different aspects of alertness which may be affected differently by different working conditions. Hypotheses are needed, then, regarding the dimensions along which alertness may vary. In considering this question we shall center attention on those aspects of behavior that relate to the general level of alertness of the organism, and emphasize actual performance rather than hypothetical capacity.

Published reports reveal a wide diversity of findings, conclusions, and opinions concerning the ways in which performance under different working conditions and environmental influences may vary as a function of time. Various theories have been advanced concerning the nature of these performance changes and various interpretations of such changes have been offered.

There are several excellent early reviews of studies of performance changes in aviation personnel. The report prepared by Finan, Finan, and Hartson (1) for the United States Air Force reviewed 588 titles and presented a brief, organized summary of the results of many tests of decrements in performance. This report forces one to conclude that prior to 1950, the results from the many and extensive tests and indices of performance decrements have contributed little to the development of tools and techniques suitable for use in studying alertness changes. More recently, significant advances have been achieved in the area of vigilance, which can be considered to be equivalent to alertness.

Many changes of a subjective nature also occur as a function of the time spent at a task. Some of the changes which have been cited include lowered feeling tone, boredom, reduced willingness to exert oneself, lowered goals, reduced motivation, increased unpleasantness of the working situation. Most of these can be summed up under what Bartley and Chute (2) aptly call "aversion" toward the task or situation.

It will be worthwhile to consider briefly the various psychological hypotheses that have been advanced as to the nature of alertness changes. The remainder of this section is devoted to presenting these hypotheses.

Mobilization of resources.--One of the most pertinent hypotheses regarding the factors underlying alertness changes is that under adverse conditions the individual is able to bring all his capacities to bear on the completion of a task. We can call this the ability to "mobilize resources." This capacity may be the major reason why so many isolated behavioral measures have failed to reveal changes of alertness as a function of time.

Decrements and impairments in performance may be masked as a result of this mobilization. The masking of important changes in the organism probably occurs primarily in relation to the major requirements of tasks. It seems reasonable to expect, therefore, that we should look for signs of decrement on those aspects of the task which are considered by the worker to be less important. These signs will be less affected by masking due to "mobilization of resources," and, therefore, will be particularly indicative of the nature and extent of general changes in the alertness and level of performance of the total organism.

Welford, Brown, and Gabb (3) lend support to the hypothesis of mobilization of resources. They suggest that the compensatory mechanism of the human are extremely complex. However, they state that even where significant effects can be shown on very simple sensory and motor tasks studied in isolation, the effects of these decrements on the larger complex task are not predictable within any acceptable level of certainty. From their point of view, changes of performance are more likely to be shown by tasks at least as complex as, if not more complex than the normal run of tasks that subjects deal with.

Loss of flexibility of set.--One of the commonly reported characteristics of performance after a period of time on the job is a loss in the ability of the worker to perceive and adjust to new aspects of the task. The worker seems unable to shift quickly and effectively from one subpart to another subpart of the task, and has difficulty performing a new task that is different from the task he has completed. It seems reasonable to hypothesize that the underlying mechanism is a loss of flexibility of set. Signs of decrement should therefore be more frequent in tasks which require the subject to exercise flexibility in moving the focus of performance from one subpart of a task to another.

Change in controlling set.--Performance decrements which are interpreted as being due to reduced levels of aspiration have been reported. The worker is satisfied with a less adequate performance. Small errors go uncorrected, even though they are perceived. The underlying mechanism is hypothesized to be a change in the general, overall controlling set of the organism. Signs of decrement should therefore be more frequent in tasks which allow small errors to go uncorrected.

Increase in conflict.--It has been proposed that there is a close correspondence between decrements in performance and the degree of subjective frustration associated with a task. The growth of frustration may be a product of an increase in conflict between the attitude, feeling tone, and other subjective components of performance and the requirements of the task on the organism. Assessments of interpersonal conflict may also reveal the cost of maintaining performance on the more critical parts of a job. We shall turn now to a neurophysiological analysis of alertness.

PART II

NEUROPHYSIOLOGIC AND BEHAVIORAL ASPECTS OF ALERTNESS

The focal point is the ascending reticular activating system. It has been firmly established that the brain-stem reticular formation has both excitatory and inhibitory functions. Studies involved with the excitatory mechanisms (4,5,6,7) have shown increased responsiveness (alertness), both behaviorally and neurophysiologically, following stimulation of appropriate areas of the reticular formation. We will assume that reasonable alertness is the normal state of the functioning air crewman. Therefore, it is the inhibitory properties of the reticular formation with which the neurophysiology of alertness is primarily concerned.

The reader should realize that the "division" of the reticular formation into inhibitory vs. excitatory areas, or regions, or mechanisms, is usually artificial. As will be discussed below, stimulation of the reticular formation often results in simultaneous excitation and inhibition of different parts of the nervous system. However, such a dichotomous division does serve the practical purpose of allowing some clarity to be achieved in a discussion of alertness.

The Evoked Potential

Supra-threshold stimulation of any of the sensory modalities produces a distinct neuro-electrical response; the evoked response or the evoked potential. By placing electrodes in or on sensory projection areas of the brain cortex, or in the sensory pathways which conduct impulses to these areas, the evoked potential can be recorded. When recorded from the cortex or the scalp surface, the evoked potential typically exhibits a short latency (8-10 msec.) as measured from the time of stimulus presentation to the time of its appearance. A series of alternating positive and negative potentials (or peaks) then follow, with the usual duration of the entire evoked potential not exceeding 500 msec.

Most measures of the evoked potential are made on the more reliable peaks occurring within the first 200 msec. The earliest of the peaks (reaching maximum amplitude at 30-50 msec.) can only be recorded from a fairly restricted portion of the brain surface. This area is considered to be the locus of sensory representation of the physical stimulus presented to the related sensory receptor. These early, or primary, potentials reach the cortical projection area rapidly via the primary sensory pathways. Potentials (peaking at 120-180 msec.) occurring after the primary potentials can be recorded from most areas of the cortex, and seem to reach it via slower reticular pathways which bypass the primary sensory relays of the thalamus. These later potentials are usually of greater amplitude than the primary potentials. Up to some maximum limit, the amplitude of the whole evoked potential (comprised of the component potentials just described) resulting from peripheral stimulation is proportional to the intensity of the stimulus. Amplitudes ranging from a few microvolts to a hundred microvolts are not uncommonly reported in the literature.

In addition to stimulus intensity, there are many other factors known to have dramatic effects on evoked potential latency and amplitude. Among them are the experimental preparation (implants or surface electrodes), the location of the recording electrodes, the sensory modality being stimulated, and the state of arousal of the organism. The last of these factors is not unrelated to the topic of the present paper. Whether or not the experimental organism is "attending" to stimulation apparently affects the amplitude of the evoked potential resulting from that stimulation.

Discrete stimuli of very short duration (milliseconds), having a definite "on" and a definite "off", yield the most distinct evoked potentials. Nevertheless, evoked potentials recorded from the surface of the cortical mantle or, as is usually the case with humans, from electrodes attached to the scalp surface, are often difficult or impossible to detect because they are superimposed on the spontaneous activity (electroencephalogram or EEG) of the brain. The development of averaging devices which summate the evoked potentials to any desired number of repetitive stimulus presentations, while "averaging out" the random spontaneous activity, has greatly enhanced the researcher's ability to study this electrical response to peripheral stimulation.

Habituation of the Evoked Potential

Accompanying repetitive stimulation with identical, nonreinforced stimuli, such as auditory clicks or flashes of light, is a decrease, over time, in the amplitude of the evoked potentials initiated by the stimuli. This diminution of the evoked potential amplitude has been observed in the cortical areas (8,9, 10,11,12) and the primary sensory pathways (13,14,15,16). Evoked potential suppression to repetitive, monotonous stimulation is operationally defined as habituation (14,17). Evidence exists that habituation is a central phenomenon and, therefore, not the result of receptor adaptation (a change in threshold) or receptor fatigue (18, 14). Habituation of the evoked potential can be obtained with widely spaced stimulus presentations which could have no cumulative effect on the receptor mechanism. Furthermore, any perceptible change in the stimulus or stimulus sequence which has led to habituation, such as a change in stimulus intensity (increase or decrease), stimulus quality, or stimulus pattern immediately evokes a full strength potential; that is, dishabituation (or inhibition of habituation) occurs. Sudden cessation of the stimulus also produces complete or partial dishabituation upon the next presentation of the same stimulus (13).

The term "nonreinforced" stimulus used in the opening sentence of this section is a very important inclusion in defining situations in which habituation of the evoked potential will occur. If the stimulus is in some way reinforced and, therefore, has some significance to the experimental subject, habituation of the evoked potential resulting from that stimulus will not occur. In conditioning, for example, the experimental subject learns to perform an appropriate response to the conditioning stimulus. During such learning the evoked potentials to this stimulus do not decrease in amplitude, and may even increase (19). Similar findings are reported for experimental situations in which human subjects acquire stimulus significance through experimental instructions. If directed to report a change in the stimulus or to react to the stimulus as rapidly as possible, habituation of the evoked potential does not occur (20,21,22). Thus, the dimension of stimulus significance or meaning plays an important role in habituation.

A typical conditioning procedure provides an example of (a) the importance of stimulus significance or meaning, and (b) evidence for viewing habituation as a central phenomenon and therefore, different from the peripheral phenomenon of receptor adaptation. The subject is first habituated to a stimulus, such as a click. Once habituation of the evoked potential is attained, this same stimulus is immediately made a (meaningful) conditioning stimulus by pairing it with an unconditioned stimulus, such as a puff of air to the eye. Following the first few such pairings, a full strength evoked potential is observed to occur to the click. Since the stimulus properties of the click are constant throughout, the dishabituation resulting from the conditioning procedure could not occur if the previous habituation had been the result of some change in the peripheral receptor mechanism. In short, it is possible to demonstrate inhibition of habituation but not of receptor adaptation.

The terminology being used in this discussion generates the question of the status of habituation as a learning process. There is not agreement as to whether habituation is a type of learning. Some researchers (14,19,17) consider habituation to be the most simple type of learning and, more explicitly, a type of negative learning in that the subject learns not to respond to nonreinforced or nonsignificant stimuli. This learning process is considered to be analogous to that occurring in the usual simple conditioning situation, except in the latter case, the subject learns to respond to reinforced or significant stimuli. Behavioral observation does indicate this to be the case. A subject in an habituation situation responds to the initially novel stimulus in that he physically orients his head, and, possibly his whole body, toward it. After a few nonreinforced presentations, however, the subject no longer orients to the stimulus and, in the absence of other stimulation, may become drowsy and even go to sleep (23,24,25). Following habituation of the behavioral responses to the nonreinforced stimuli is the above mentioned habituation of the evoked potentials generated by these stimuli (15). However, in the conditioning situation, where the stimulus becomes significant through appropriate shaping and reinforcement procedures, the subject remains alert and, as discussed earlier, evoked potential suppression is not observed to occur.

Other theorists, on the basis that learning is often defined as a relatively permanent change in behavior, do not consider habituation to be a type of learning (26). Such a position is somewhat justified in that, habituation, while it can be prolonged, is never permanent. Recovery or dishabituation of the evoked potential to a stimulus does occur following a period of rest or interpolated activity (15). However, rehabituation to the same stimulus seldom requires as many trials or stimulus presentations as did the first habituation session. And each succeeding session requires fewer and fewer presentations to obtain the same degree of habituation (19). Thus, there is some "carry-over" effect which does indicate habituation to be a learning process.

Consideration of all the above findings suggest the existence of some central mechanism which has a sensory-gating function, suppressing sensory input following presentation of nonreinforced or nonsignificant stimuli while offering no such resistance to input generated by reinforced or significant stimuli. The relevance of such a mechanism to attentional processes is obvious. Thus, investigators have attempted to determine what this mechanism is, how it functions, and where in the sensory pathway it has its affect. One

of the most prolific researchers in this area has been Raul Hernandez-Peon. As will be discussed below, he and his associates have constructed a strong case for intrusting the brain-stem reticular formation, a region where impulses of all sensory modalities converge with this sensory-gating function. As mentioned at the beginning of this section, this group of investigators has found habituation of the evoked potential to occur in all of the primary sensory pathways of the nervous system. Furthermore, they have found habituation of the evoked potential to occur first at the "highest" level of the pathway; at the cortical sensory area. With further stimulation, evoked potential suppression is then observed to occur successively at lower and lower levels of the pathway, occurring last at the first afferent synapse (27,28,29).

Stimulus Variables

Before further pursuing the major topic, it may be of benefit to the reader to briefly discuss important stimulus variables in this area of research. In most of the studies, initiation and duration of sensory stimulation is controlled by an audio oscillator generating square wave pulses of desired duration. Such pulses yield "crisp" stimuli which result in well defined evoked potentials, as discussed earlier. Stimulus duration varies anywhere from a few hundredths of a millisecond (30) to several milliseconds (31). Likewise, intensity and rate of stimulation, the number of experimental sessions, and the duration of an experimental session vary greatly from study to study.

A few studies of a parametric nature have been reported. Galambos (30), in a study investigating the suppression of auditory nerve activity by electrical stimulation of efferent fibers located in the floor of the medulla, reported the effects of varying (a) strength of auditory stimulation (intensity of clicks), and (b) frequency and intensity of shock to the medullary fibers. For constant shock values, the auditory nerve response was more likely to be abolished when the click was of weak intensity. With weak clicks, fewer stimulus presentations were required for complete evoked potential suppression. Increased rate of suppression of the evoked potential to the clicks was found as the intensity and/or frequency of medullary stimulation was increased (to some upper limit), while holding auditory stimulation constant. Sensory stimulation at the fast rates leads to habituation of the evoked potential sooner than do slow rates of stimulation (19,32). While most studies use a constant rate of stimulus presentation, Webster et al. (32) found a regular rate of stimulation to not be a necessary condition for habituation to occur. However, very intense stimulation seldom leads to habituation of the evoked potential. Recording from the cochlear nucleus, inferior colliculus, and medial geniculate body, Webster (33) more recently reports an instance in which weak auditory stimuli did not produce larger evoked potential decrements than relatively stronger stimuli. Also, dishabituation was not observed as a result of changes in rate of auditory stimulation.

While describing the stimulus parameters of each study discussed in the present paper is prohibitive, it is important that the reader realize that these factors are of significance and often make comparison of studies difficult or impossible. In brief, few of these studies are primarily interest in the rate of evoked potential habituation, but in whether or not habituation to ongoing stimulation occurs in the experimental situation or preparation under investigation.

Afferent Neuronal Inhibition

Perhaps the earliest study indicating that the reticular formation is at least partially responsible for the control of sensory input was performed by Hagbarth and Kerr (34). With domestic cats serving as subjects, they found that electrical stimulation of the midbrain reticular formation reduced the amplitude of postsynaptic afferent volleys recorded from lumbar dorsal roots. It should be noted that this same reticular stimulation simultaneously produced a general behavioral alerting of the organism and activation of the EEG (low voltage, fast activity) as first reported by Moruzzi and Magoun (7). The behavioral alerting and concomitant neurophysiological arousal response resulting from reticular stimulation appears identical to that observed upon the presentation of a novel stimulus to a relaxed subject. Results similar to those of Hagbarth and Kerr have now been reported for all modes of sensory input at all levels of the central nervous system (9,10,35,36,37,38,39,40).

Thus, the combined findings of (a) the brain-stem reticular formation being a center of convergence for impulses of all sensory modalities, (b) behavioral and evoked potential suppression to nonreinforced or nonsignificant stimuli, (c) a similar suppression of sensory evoked potentials during and immediately following direct stimulation of the reticular formation, (d) the increased behavioral alertness observed during and immediately following reticular stimulation or presentation of a novel stimulus, and therefore, (e) the apparent relationship between evoked potential amplitude and whether or not the organism is attending to the stimulus which initiated the evoked potential, generated Hernandez-Peon's theory of afferent neuronal inhibition. This theory views the reticular formation as a highly important sensory integration center which exhibits centrifugal filtering influences upon information it receives from all sensory pathways (41). At a given moment, only a limited number of incoming signals reach the reticular formation, and all others are excluded. "The exclusion of afferent impulses from sensory receptors takes place just as they enter the central nervous system. Therefore, the first sensory synapse functions as a valve where sensory filtering occurs (41, p. 515)." But this "valve" is controlled by the reticular formation.

Such control is obtained through efferent inhibitory fibers which course from the reticular formation to the first sensory synapse. Some evidence for the existence of such fibers is presented below. Thus, a type of feedback loop may be conceived, with the afferent fibers from the first sensory synapse to the reticular formation representing the ascending component of the loop, and the efferent inhibitory fibers coursing from the reticular formation to the first sensory synapse representing the descending (centrifugal) component. It is further assumed that efferent inhibitory fibers have similar effects at all of the synaptic junctions of a primary sensory pathway (27,11). This additional assumption would explain the findings discussed earlier that habituation of the evoked potential is first observed to occur at the cortical receiving area and then successively at lower brain levels. The inhibitory effects of the centrifugal fibers would have a cumulative suppression effect on the incoming evoked potential as it traversed more and more synaptic junctions of the sensory pathways.

It is evident that Hernandez-Peon and his colleagues consider the reticular formation as controlling important sensory integrative mechanisms. Impressive evidence for this position has been reported in a

multitude of studies. Perhaps the studies utilizing anesthetics and lesioning techniques, more than any of the others, lend support to this position. Unless otherwise stated, all of the studies to be discussed used domestic cats as subjects.

Drug Studies

It has been known for some time (42) that central anesthetics yield an enhancement of cortical evoked potentials. Recording from subcortical levels of specific afferent pathways has revealed that, under the influence of central anesthetics, enhancement of sensory evoked potentials occurs at all levels of the central nervous system, including the first sensory synapse. Hagbarth and Kerr (34) report that the evoked potentials recorded from spinal afferent neurons are increased in amplitude during pentobarbital or chloralose anesthesia. Similar enhancement of evoked potentials during pentobarbital anesthesia has been observed at the gracilis nucleus in the medulla and the lateral geniculate body in the thalamus (31). As long as the effects of the central anesthetic are present, no habituation of the evoked response is observed. If habituation has occurred just prior to the administration of a central anesthetic, complete recovery (or dishabituation) is observed after the anesthetic has taken effect (19). These observations imply that central anesthetics release sensory relay stations from inhibitory influences which act tonically during wakefulness. In an effect to locate the orig[illegible] of such tonic inhibitory influences, a variety of lesioning studies have been performed.

Lesion Studies

Hernandez-Peon and Brust-Carmona (19) report a comprehensive study in which habituation of evoked potential initiated by tactile stimulation was investigated following removal or complete sectioning of various levels of the central nervous system. The evoked potential was recorded by means of electrodes implanted in the lateral column of the thoracic segment of the spinal cord. It was first established that habituation would occur at the spinal level in intact animals. Following removal of the neocortex, habituation of the spinal evoked potentials was observed to occur at the same rate (or sometimes faster) as it had in the intact subjects. Similar results were found for the decerebrate preparation. (In general, structures present in the decorticate, but not in the decerebrate are the forebrain, the temporal lobes, and the diencephalon.) Dishabituation was also observed in both of these preparations following a slight increase in stimulus intensity. The use of an increase in stimulus intensity to demonstrate the occurrence of dishabituation was an unfortunate selection. It would have been much more significant to find the same result using a slight decrease in stimulus intensity.

If afferent neuronal inhibition results from centrifugal inhibitory influences proceeding from the reticular formation of the brain-stem, then the spinal responses habituated in the above mentioned decerebrate preparation should be enhanced by interrupting the postulated descending inhibitory path to the spinal sensory neurons. This is what Hernandez-Peon and Brust-Carmona found. Following severance of the spinal cord at the second cervical level, the tactile evoked potentials were enhanced to their original size. Unfortunately, no analogous attempts were made to investigate whether or not dishabituation occurred as a result of sectioning at the brain levels above the reticular formation. The theory of afferent neuronal inhibition would predict there to be no dishabituation of evoked potentials to stimuli which the subjects were habituated to prior to the surgical manipulations.

Other studies have investigated the effects of lesions in the reticular formation. Extensive lesion of the mid-brain reticular formation prevented acoustic habituation at the cochlear nucleus (43). If habituation had occurred previous to lesioning, dishabituation occurred immediately following its administration. Some lesioning studies (41) indicate that different areas of the reticular formation do not participate to the same extent in the development of habituation in the different sensory pathways. Mesencephalic tegmental lesions prevent habituation of olfactory activity whereas lesions involving the pontine tegmentum do not prevent olfactory habituation. These same lesions have just the opposite effect on vestibular activity. Pontine lesions prevent vestibular habituation while mesencephalic lesions do not. These findings suggest an anatomical and/or functional organization of the sensory integration properties of the reticular formation.

Distraction Studies

Perhaps the most well-known study reported by Hernandez-Peon is of this type. As in all of the studies discussed above some type of discrete unreinforced stimulus is repetitively presented to the experimental subject and the evoked potentials resulting from this stimulation are recorded from some point in the sensory pathway. A distracting or novel stimulus, usually of a different sensory modality, is then presented to the subject and changes in the evoked potential are noted. The classic study of this type was performed by Hernandez-Peon et al. (31). Evoked potentials to auditory clicks were recorded from the dorsal cochlear nucleus. Long before habituation to the clicks could occur, visual (mice), olfactory (fish odor), or somatic (shock) stimuli were presented concurrently with the clicks. During presentation of any of the distracting stimuli, the amplitude of the evoked potentials were greatly depressed. Removal of the distracting stimuli led to immediate recovery of the auditory evoked potentials. Similar findings have been reported for visual evoked potentials with acoustic distraction (11), olfactory or somatic evoked potentials with visual distraction (16), and tactile evoked potentials with visual, olfactory, or acoustic distracting stimuli (44).

In all of these studies, presentation of the distracting stimuli led to behavioral arousal of the subjects. The suppression, and in some cases disappearance, of the evoked potential is assumed to result from the subject paying attention to the novel stimulus and ignoring the other. That the animal is alerted by the novel stimulus is supported by the fact that the resulting behavioral alerting response is like that resulting from direct reticular stimulation and is accompanied by an activated EEG pattern. These same results are found in decorticate cats and in cats with destruction of the specific auditory pathways at the mesencephalic level (45,41).

Jane, Smirnov, and Jasper (46) investigated the effects of distraction stimuli presented to the same sensory modalities in which ongoing stimulation was occurring. Auditory clicks and visual flashes were

presented simultaneously. Evoked potentials to these stimuli were recorded from the auditory and the visual cortices, and the medial and lateral geniculate bodies of the thalamus. Live rats and recorded rat squeaks served as the distraction stimuli. Presentation of either of the distracting stimuli produced, at all recording sites, evoked potentials of greater amplitude than those produced before or after the presentation of the distracting stimulus. This result challenges the existence of a sensory-gating mechanism and, instead, indicated an overall diffuse alerting of the organism. It should be noted that these researchers measured evoked potential peaks of only 20-30 msec, latency from the stimulus onset and, therefore, the results cannot be attributed to measuring secondary peaks resulting from diffuse reticular pathways.

While the authors make little of it, it is also important to note that they found some facilatory interaction or cross-talk between auditory and visual pathways. Amplitudes were lower, for instance, when clicks were presented alone than when both clicks and flashes were presented simultaneously. Perhaps this intermodal facilitation was maintained during presentation of the distraction stimulus. A related possibility is that the sensory-gating mechanism may not be capable of suppressing input through one sensory modality while allowing simultaneous input of another modality to pass on unhindered. Great effort was taken in this study to make the two stimuli as simultaneous as possible, including a 10 msec. delay in the presentation of the click to allow for the longer input time of the visual system due to the photo-chemical process of the retina. Thus, upon receiving such "time-locked," dual modality stimulation, the sensory-gating mechanism may, in the interest of the organism, suppress neither of the stimuli if one of them is of significance or novel to the organism, or if one of them is sharing a pathway carrying other novel or significant stimuli. Whether or not this hypothetical explanation of the Jane et al. results is compatible with the previously suggested functional organization of the reticular formation is a matter of speculation. But if the theory of afferent neuronal inhibition is to be of any utility, it must be capable of explaining and predicting the results of both inter-modality and intra-modality distraction studies. Whether or not it successfully handles the latter is yet to be determined.

Efferent Inhibitory Fibers

A basic premise of the theory of afferent neuronal inhibition is that the reticular formation is capable of inhibiting sensory input at the afferent synapses by means of efferent inhibitory fibers under its control. That electrical stimulation of the reticular formation yields a suppression of evoked potential amplitude offers some indirect evidence for the existence of such fibers. A few studies offer more direct evidence. Galambos (30), recording from the round window of the cochlea, found electrical stimulation of a very restricted area near the floor of the medulla to suppress the amplitude of evoked potentials generated by auditory clicks. Histological investigation revealed this area to be located in the olivo-cochlear pathway, which was first described as an auditory efferent pathway by Rasmussen (47,48). The fibers of this pathway are known to end in the cochlea, but exactly where in that organ is not known. If this pathway was cut peripheral to the site of stimulation, habituation of the evoked potential could not be obtained. Control lesions made in closely adjoining areas did not prevent habituation. Thus, these results suggest that impulses transported by the olivo-cochlear fibers are somehow required for habituation of evoked potentials recorded from the round window.

This finding, while not necessarily in conflict, would not be predicted from the theory of afferent neuronal inhibition. The theory considers central control of sensory input to occur no sooner than at the first afferent synapse. Advocates of afferent neuronal inhibition consider the efferent inhibitory fibers to be anatomically within or immediately adjacent to the primary sensory pathways. Spinelli, Pribram, and Weingarten (49) have reported a most intriguing finding which supports this position. Evoked potentials were recorded from the optic nerve of the retina when a curarized cat was stimulated with auditory clicks to its ear. Since there was no discrete stimulation to the visual system, these evoked potentials were interpreted as being efferent impulses sent out to the retina from the brain while it was processing the input of the auditory pathway. Most recently, Irvine and Webster (50) presented evidence that the olivo-cochlear bundle does not function as a gating mechanism in the auditory system.

Other Theories and Research

For the most part, the findings of the behavioral and neurophysiological research on vigilance and alertness support a position which considers the reticular formation to be a sensory integration center, capable of suppressing input generated by nonsignificant stimuli by means of efferent inhibitory fibers coursing from the reticular formation to synapses of the afferent sensory pathways. However, this position, and the research upon which it is based, is not without its critics. A fundamental point of dispute is whether habituation of the evoked potential is a central or peripheral phenomenon. Obviously, Hernandez-Peon and his colleagues consider habituation to occur centrally. The peripheral viewpoint considers habituation to occur outside the central nervous system, as a result of the activity of structures or mechanisms peripheral to the sensory receptor.

More specifically, the peripheral explanation of habituation states that less sensory input enters the primary sensory pathway. Mechanisms peripheral to the receptor, but which are in someway involved in sensory input transmission or transduction, are considered responsible for this reduction of input to the central nervous system. In the auditory system, for example, it is well founded that upon presentation of a very loud auditory stimulus, the middle ear muscles (tensor tympani and stapedius) contract, thereby yielding a change in the articulation of the small bones of the middle ear. These bones transmit auditory input from the ear drum to the oval window of the cochlea. The change in articulation is a protective mechanism which prevents damage to the receptors in the cochlea by over-stimulation. According to the peripheral position, it is a similar activity of these middle ear muscles which accounts for auditory habituation. An analogous mechanism in the visual system would be the pupil.

The bulk of the research which attempts to resolve this dispute has selected the auditory system as a means of attack. This choice was most likely governed by the relatively easy access to peripheral structures (cochlea and middle ear muscles) of the auditory system. Therefore, research involving the auditory modality will be utilized in this discussion of central vs. peripheral explanations of habituation. The methodology used by advocates of both viewpoints consists of three fundamental steps: (a) It is first con-

firmed that habituation will occur in the intact organism; (b) the structures or mechanisms assumed by the peripheral explanation to be responsible for habituation (the middle ear muscles of the auditory mode) are removed or rendered nonfunctional; (c) observations are made to discover whether or not dishabituation occurs as a result of step (b), or if habituation can be obtained following step (b). This procedure would seem to offer unequivocal results. Such has not been the case. Proponents of both the central and the peripheral positions consistantly report results which support their respective viewpoints.

Galambos (30), recording from the round window, found a contraction of the middle ear muscles to accompany evoked potential suppression. Upon repeating the study in curarized animals with the middle ear muscles removed, Galambos found evoked potential suppression to still occur. Moushegian et al (12), recording from the auditory cortex, also found habituation of evoked potentials following removal of the middle ear muscles. Dishabituation was then observed to occur upon making the clicks conditioning stimuli. Visual distraction during the conditioning session again led to suppression. These findings, of course, concur with a central explanation of habituation. Hugelin, Dumont, and Pailas (51) replicated Galambos' finding of auditory habituation previous to middle ear muscle removal. However, they found very little or no habituation of auditory evoked potentials following removal of the muscles. Guzmon-Flores, Alcaraz, and Harmony (52) report findings similar to those of Hugelin et al. Thus, these researchers advocate a peripheral explanation of habituation.

More recent studies offer some evidence for rejecting the peripheral explanation of evoked potential habituation. Worden and Marsh (53) and Worden, Marsh, Abraham, and Whittlesey (54) found the position of the subject's head within the field of the sound source to be an important variable in recording auditory evoked potentials. Without proper control of this factor, variation in evoked potential amplitude, unrelated to stimulus significance, was found as the subject's head was moved from position to position with respect to the sound source. The greatest effect of position changes occurred at the lower auditory centers; the cochlear nucleus and the inferior colliculi. Ear phones were then developed which held acoustic input constant. Using this improved control of the experimental situation, Marsh and Worden (55) looked at habituation to auditory clicks. For evoked potential samples with the subjects in an alerted state, no consistent effect was observed at the cochlear nucleus, although a progressive decrease in amplitude was found at the auditory cortex. This finding (and those previously discussed in which habituation of the evoked potential was found to occur sequentially at successively lower brain levels) suggests that peripheral mechanisms are not responsible for evoked potential suppression. If habituation were the result of peripheral mechanisms, any suppression effect would be expected to occur at all levels of the central nervous system simultaneously. Marsh and Worden also report that evoked potentials in non-alerted samples were of greater amplitude than in alerted samples. This finding is compatible with previous results, in that the reticular formation is less active in non-alerted organisms, and is, therefore, yielding less tonic inhibitory influences on primary sensory pathways.

Webster et al. (32) have also attempted to clarify the central vs. peripheral controversy. Again audition was the sensory mode selected for study. These researchers point out that a premise which one must accept if he advocates the peripheral explanation is that habituation of the evoked potential is produced by temporal conditioning of the middle ear muscles, since the latency of these muscles is far greater than the duration of stimuli usually employed. This implies that a constant interval between stimuli is necessary for habituation to occur. As discussed earlier, these investigators found a regular rate of stimulization to be an unnecessary condition for the occurrence of habituation.

Another interesting finding is reported in the Webster et al. study. Sodium pentobarbital did not abolish habituation obtained prior to its administration. This finding, of course, is in direct opposition to all previous reports of the effects of barbituates upon habituation. Furthermore, Carmel and Starr (56) have shown barbituates to block the action of the middle ear muscles. Taken together, these studies offer results which are difficult for both the central and the peripheral positions to interpret.

Thus, the trend seems to indicate that habituation of the evoked potential is the result of central mechanisms, with the reticular formation playing a most important role. But, it would be naive to state that higher brain structures, when present, have no influence on the reticular formation and, therefore, on habituation. As with electrical stimulation of the reticular formation, many studies have found stimulation of the cortex to suppress evoked potential amplitude resulting from peripheral stimulation (37,57). However, based upon the lesioning studies discussed above in which habituation was obtained following removal of brain centers above the reticular formation, Hernandez-Peon and his collaborators do not consider these higher centers as necessary for the occurrence of evoked potential habituation.

There are researchers who do consider the higher brain centers, including the cortex, to play a necessary and important role in habituation. The research of these cortical theorists, however, has emphasized the study of habituation of the behavioral orienting response (briefly mentioned earlier) rather than the study of evoked potential habituation (see Lynn (23), for a review of this research). Sokolov (58), for instance, views the cortex as a high level comparator which stores "nervous models" of past stimulation. If sensory input matches the "nervous models" or replicas of nonreinforced or nonsignificant stimuli deposited in the cortex as a result of previous stimulation, inhibitory impulses are sent from the cortex to retard the input of the afferent sensory collaterals entering the reticular formation and, thus, prevent or reduce the orienting response. If the stimulus is novel, activation of the reticular formation by the afferent sensory collaterals is not prevented, thereby allowing the orienting response to occur. Obviously, if one desired, this theoretical model could also be applied as an explanation of evoked potential habituation or afferent neuronal inhibition. However, since habituation of the orienting response occurs before and in many fewer trials than evoked potential habituation, Hernandez-Peon (14) suggested that different mechanisms are involved in habituation of the orienting response and afferent neuronal habituation. Based upon current knowledge, such a suggestion seems premature. Jouvet (59), another theorist who stresses the importance of the cortex in habituation of the orienting response, found that cortical, mesencephalic, and cochlear evoked potentials persisted undiminished in amplitude after EEG activation had habituated, and that complete habituation of the evoked potential was not possible in neodecorticate animals. He concluded that habituation of the evoked potential represents an inhibitory effect on the reticular formation by the cortex.

The studies upon which the theory of afferent neuronal inhibition is founded have restricted peripheral stimulation to the use of simple stimuli, such as clicks, shocks, or flashes of light. But, in the intact organism, it is also possible to obtain habituation to more complex stimuli, such as a pattern of tones (for instance, high-low-high). Dishabituation occurs to a change in the pattern (for instance, high-high-high). It has been shown in learning studies that such auditory pattern discrimination requires at least part of the auditory cortex to be present, since its complete removal prevents such learning (60). Thus, the findings by advocates of afferent neuronal inhibition that higher structures of the central nervous system are unnecessary for the occurrence of evoked potential habituation may contain a stimulus artifact, in that only very simple stimuli were used. It is difficult to exclude the cortex as not being involved in habituation, particularly when more complex stimuli are involved. A study by Rusinov and Smirnov (16) offers a dramatic example. Human subjects were first completely habituated to words of similar meanings (but different sounds). Upon presentation of words with different meanings (but similar sounds), dishabituation occurred immediately. Apparently borrowing somewhat from the Sokolov model, Bower (62) offers an interesting speculation.

> Depending upon the complexity of the input stimulus, the comparison of input to stored replica goes on at different levels of the brain. The assumption would be that the neural structures responsible for habituation to a particular stimulus are at the same level as those required for its discrimination (p. 445).

Human Studies

The use of human subjects offers distinct advantages in the study of sensory habituation and, even more so, attention. Through instructional set, it is possible to study voluntary attention (alertness) to selected stimuli. Hernandez-Peon and Donoso (63,64) recording from within the visual cortex, studied visual evoked potentials to flashes of light. The amplitude of the evoked potentials were significantly reduced while the subjects were performing arithmetic calculations. When the subjects arrived at a solution to a problem, the evoked potential amplitude recovered. The amount of amplitude suppression occurring during mental work was proportional to the difficulty of the task; the more difficult the problem, the greater the suppression. Similar results were found when emotional excitement was used in place of mental work. Hernandez-Peon (28) found simple conversation on some topic of interest to the subject to reduce the amplitude of cortical evoked potentials resulting from tactile stimuli.

Vigilance situations, like habituation studies, present an excellent means of studying alertness and attention in human subjects (65,66). A vigilance task may by defined as a monotonous situation in which the subject must observe repetitive stimulus presentation, usually for a long period of time, (such as one or two hours). Ocassionally, the stimulus will change in some defined way, and this is defined as a critical stimulus which the subject must detect and report. Depending on the difficulty of the task, detection performance usually deteriorates over time. Most researchers in this field assume the performance decrement to be the result of changes in the observer's state of attentiveness.

The similarity of the habituation situation and the simple vigilance situation is striking, and has been previously noted by Frankmann and Adams (67), Mackworth (68), and Scott (69). In both situations, the subject is monotonously presented with nonsignificant stimuli over a prolonged period of time. Only very seldom does a significant stimulus (signal) occur in the vigilance situation. Amplitude suppression of the evoked response has been found to occur in both the habituation and the vigilance situation. And, both the performance decrement in vigilance and the evoked response amplitude decrement in habituation generally produce a negatively accelerated function over time. Findings analogous to those of dishabituation have also been reported for the vigilance situation. A rest interval results in temporary performance improvement in a vigilance task (70,71). The occurrence of an extraneous or novel stimulus has also been found to temporarily improve detection performance (68).

Haider et al. (10) recorded visually evoked potentials from the scalp of subjects performing a vigilance task. Flashes of light were presented to the subjects, who were instructed to press a level whenever a dim flash (critical stimulus) occurred. As detection efficiency diminished over time, the amplitude of averaged evoked potentials to non-signal stimuli decreased and latency increased. Brief fluctuations in vigilance performance (attentiveness) during the course of the task also were accompanied by corresponding changes in evoked potential amplitude to non-signal stimuli. Averaged evoked potentials to missed or non-detected stimuli were of lower amplitude than those to detected critical stimuli. This last finding was present during both early and late stages of the task, and therefore, was not dependent on the overall decline in vigilance performance.

Spong et al. (22) presented click and flash stimuli alternately to human subjects who were instructed to selectively attend to stimuli of only one of the two modes. Stimuli of the non-attended-to mode were of constant intensity, while an occasional weak intensity stimulus was presented in the attend-to mode. The subjects were to detect the weaker, or critical stimuli. Responses to flashes recorded from the occipital area were larger when attention was directed toward visual stimuli, and responses to click stimuli recorded from the temporal area were larger when attention was directed toward auditory stimuli. Similar findings are reported by Morris (72), who also presented click and flash stimuli, and Satterfield (73) who presented auditory and tactile stimuli. Using a task assumed to require a high degree of attention, Davis (20) found auditory evoked potentials to be enhanced in amplitude by instructing the listener to make a difficult auditory discrimination.

Summary

Current research efforts are being directed at differentiating the effects of general arousal and of specific attention on the averaged evoked response. Using simple but ingenious experimental designs, Eason and his associates (74,75,76) have found the evoked response to be related to both general arousal and specific attention. The combined effects of increasing or decreasing arousal and shifts in attention toward or away from the evoking stimulus determine the overall net change in evoked response amplitude. Similar efforts involving the auditory modality have been conducted by Picton and Hillyard (77) and Wilkinson and Lee (78).

The mechanism responsible for the gating of significant and nonsignificant stimuli has yet to be satisfactorily defined. While a conservative position, the research which has been discussed seems to indicate that sensory gating can occur at several points in the sensory pathway, including (a) peripheral to the sensory receptor, (b) at the sensory receptor, and (c) at synaptic junctions of the sensory fibers.

The theory of afferent neuronal inhibition is the most complete theory attempting to explain habituation and suppression of the evoked potential. The reticular formation is considered to control sensory input by means of efferent fibers which inhibit input at sensory synapses. Of the three reported types of gating listed, this explanation is the most parsimonious. But, it cannot be denied that evoked potential suppression at the receptor, and functional changes of peripheral sensory structures have also been observed to accompany repetitive stimulation. Certainly, the reticular formation participates in the gating of sensory input. Ideally, it receives information from all sensory inputs, as would be expected of a sensory-gating mechanism. The fact that direct stimulation of the reticular formation yields cortical activation and an alert organism, while stimultaneously suppressing input from ongoing stimulation, also makes this "structure" a candidate for playing some role in the gating of sensory input.

But, it is likely that higher central nervous system structures are also involved in the gating process. While offering some methological problems, studies which utilize stimuli of a more complex nature than those used in most of the studies discussed above may reveal this to be the case. In the study of visual input, for instance, tachistoscopic presentation of such stimuli would still allow the researcher to trace the sensory input in the form of the evoked potential. Many of the studies upon which afferent neuronal inhibition is founded should be replicated, thereby taking advantage of recently developed instrumentation. The data obtained from these newer devices are not only more reliable, but are more readily available to quantification and statistical analysis. Unfortunately, in many of the studies discussed in this paper, only a visual analysis was performed on the data.

The human subject, while offering only evoked potential data recorded from the scalp, is unique in the study of attention. Stimuli can gain significance (or nonsignificance) for the human subject simply through appropriate instructions. Thus, a type of control is achieved which is not readily available when using non-human subjects. Of course, only through the collection and analysis of comparative data, both behavioral and neurophysiological, will the physiological mechanisms of attention come to be understood.

PART III

DIET AND PILOT ALERTNESS

The relationship between diet and the behavior of man has been shown to be both direct and indirect, multifactorial and highly complex. In considering the breadth of this relationship, one must consider the impact of deficiencies or excesses of more than forty known nutrients required by the body, the frequency with which these nutrients are consumed, the overall balance of nutrients, and the impact of many environmental factors which can effect the utilization rates of these nutrients. Adding to the complexity of the problem is the ability to measure those physiological and psychological parameters which contribute to coordinated organized goal-directed behavior which includes as a major component, alertness. For the purpose of this discussion, only four areas of consideration will be discussed; (1) short-term nutrient deprivation, (2) long-term nutrient restriction, (3) diets deficient in one or more nutrients, and (4) diets lacking appropriate nutrient balance.

Short-Term Nutrient Deprivation

When an individual fails to consume food for periods longer than six to eight hours, his energy metabolism reverts almost entirely to body stores to carry on body functions and work. Absorption of nutrients from the gastrointestinal tract becomes insignificant at this point in time. Under circumstances where the individual is asleep or at complete rest and fasting for six to eight hours, the body stores of carbohydrates as well as blood glucose levels remain stable. If on the other hand the individual is engaged in moderate to high activity, this level will be substantially reduced. Since the central nervous system uses blood glucose almost exclusively for fuel (79), it would be anticipated that this system would be adversely affected during total nutrient deprivation. This hypothesis is supported by an increase in the occurrence of hypoglycemia in fasting individuals performing moderate activity (80,81). An attempt to demonstrate hypoglycemia in flying personnel who did not eat breakfast was unsuccessful as reported by Robbins et al. (82). Brozek (83,84) has reported that deterioration in both coordination and speed of movements were experienced during four days of acute starvation whereas strength measurements remained essentially unchanged In studies by King et al. (85) it was shown that cortico-retinal function and psychomotor functions were significantly reduced in subjects having no breakfast and exposed to an altitude of 15,000 feet, whereas subjects having a high carbohydrates breakfast and exposed to the same altitude showed no impairment.

First we must ask, how relevant is nutrient deprivation to flying operations? Our observation of flying personnel throughout recent years has convinced us that nutrient deprivation is relatively frequent. In some aircraft systems, particularly high altitude and fighter bomber aircraft, food systems are entirely make-shift despite 10 and 12 hour mission profiles. Pilots flying these aircraft have confided that frequently they do not eat up to 12 hours preflight to avoid the necessity of defecating in flight. Pilots who fly transport aircraft also have a problem in that they are affected by multiple time zone changes. As a result, these pilots undergo shifts in circadian rhythm and frequently omit meals. The inability to obtain appealing food may also contribute to omitting meals. Frequently, crewmembers fly one leg of a mission and arrive during the normal breakfast hours of that location, although their biological time is midday. Rather than eat a second breakfast, they elect to omit the meal.

Tuttle et al. (86,87,88) have shown that the omission of breakfast causes an increase in choice reaction time and tremor magnitude and a decrease in maximum work output. Studies by Haggard and Greenberg (89) have demonstrated that performance as measured by physical efficiencies is lowest prior to breakfast and highest one hour after breakfast of day long measurements. The efficiency curves showed a decline each hour after the high point until lunch was consumed. One hour after lunch, efficiency rose to a high level

and then showed a decline again throughout the afternoon. However, subsequent studies by other investigators have not confirmed these results (90).

The implications of these data are that some performance functions, particularly those involving high levels of central nervous system involvement, are adversely affected by nutrient deprivation. The degree to which these impaired functions are related to pilot alertness, however, may be conjectural. The number of pilots who routinely skip breakfast is also relatively high. Some claim it is a matter of convenience while others claim they omit breakfast for weight control. The ability of the body to adjust to the omission of breakfast without incurring any performance decrement is unknown. However, it seems certain that an individual who routinely eats breakfast will show a significant performance decrement if he should omit breakfast. Another situation that should be taken into account is the individual who is crash dieting to meet his weight standard on the occasion of his annual physical. There are some individuals who literally stop eating for periods of several days prior to their annual physical to effect maximum weight loss. The final consideration is the individual who has consumed significant amounts of alcohol the previous day and does not have an apetite for food. Normally, the activity level associated with flying an airplane is not high. Therefore, the utilization of blood glucose by muscle tissues would be low and hypoglycemia would not be anticipated. However, under circumstances where high speed maneuvers are required, some individuals may suffer hypoglycemia (91). Under these conditions, alertness will definitely be effected. Marks (79) characterized the symptoms of acute hypoglycemia as a vague sense of ill health, anxiety, panic, feeling of unnaturalness, and detachment from the environment. These symptoms are accompanied by palpitations, restlessness, nausea, or hunger. Objectively, there is tachycardia, facial flushing, sweating, unsteady gait, abnormal behavior, and alterations in consciousness. He further characterized the symptoms of subacute hypoglycemia "as a gradually developing sense of lethargy and somnolence associated with a reduction of spontaneous activity, conversation, and movement."

Dehydration is of particular concern in conditions of total food deprivation. Most individuals consume the major portion of their water during mealtime. Food deprivation not only results in a decrease in beverages consumed, but also water contained in the diet. The average diet contains approximately one liter of water and results in the production and/or release of approximately one half liter of metabolic water. This quantity of water is equal to approximately one-half of the daily intake. Consequently, fasting individuals are frequently also dehydrated. Adolph et al. (92) have demonstrated that a loss in body weight due to dehydration of 1% to 5% can cause impatience, sleepiness, and anorexia among other symptoms. It is obvious that alertness of such an individual will be impaired.

Long-Term Nutrient Restriction

In defining long-term nutrient restriction, it is implied that the diet may be of optimum balance of nutrients but insufficient in quantity. Consequently, this discussion will be limited to situations where the individual will consume insufficient calories to meet his body's need for growth, maintenance, and work. Under these conditions, the body stores of energy which are essentially fat and protein will be consumed for fuel. Such dietary practices have been seen among pilots living in combat zones during the Vietnam War. It was common to observe weight losses of 20 to 30 pounds among individuals who were within current weight standards at the time of their assignment. Occasionally, pilots who are significantly overweight, undertake a long-term weight reduction program and lose as much as 20 or 30 pounds of weight. Significant reduction is also common among individuals assigned to extremely hot or extremely cold environments. Finally, individuals forced to live under long-term survival conditions frequently undergo the extremes in nutritional deprivation. In all these situations, a negative calorie balance exists which frequently results in significant negative nitrogen balance as well.

Research on changes in body composition associated with even short-term nutrient restrictions has shown a loss of body lean mass in conjunction with body fat mass. These data further indicate that in nutrient restriction, losses of lean are more significant in individuals having a lower percentage of body fat.

In recent years there has been intense interest in the relationship between long-term nutrient restriction and behavior. Extensive animal research has been conducted to determine the input of nutritional deprivation at various periods of infancy on growth processes (93,94,95,96).

Some research has been accomplished to define the impact of long-term nutrient restriction on mental performance of adult humans. Brozek (83) has reported that prolonged calorie restriction caused a significant loss in strength but only small decrements in eye-hand coordination and speed of movement. Rogers et al. (97) reports that there was substantial loss in work performance during studies in extreme cold where nutrient restriction was also a factor. This investigator attributes this loss of performance to a combination of factors including dehydration, hypovolemia, hypoglycemia, ketosis and acidosis. Rogers points out that a significant adjustment occurs in the individual's condition after the third or fourth day and all of the above biochemical observations make an adjustment toward normality. During these three to four day periods, the individual is depressed, shows signs of anxiety and shows other psychological changes. This research shows that a diet high in carbohydrates versus protein and fat provides significant improvement from both the biochemical and psychological changes.

There is an abundance of research dealing with the effects of long-term nutrient restriction on physical performance (98,99,100,101). In all these studies, performance was significantly reduced and the reduction was dependent on the level of restriction and the length of time the restriction was imposed. Unfortunately, most of these studies did not incorporate measurements of psychomotor behavior. It appears, however, that psychomotor behavior is less effected by long-term nutrient restriction than physical performance, particularly if a major portion of the calories consumed are carbohydrates.

Diets Deficient in One or More Nutrients

The relationship between dietary deficiencies and alertness has received only limited investigation. Some inferences can be drawn, however, from data obtained from more general research on the roles of individual nutrients in the body. In considering the vitamins, a majority of these biochemical compounds form

specific co-enzymes needed in various chemical processes. Although there are probably requirements for each of the vitamins in nerve tissue, a few appear to play a critical role. Vitamin A, nicotinic acid, vitamin B12 and thiamine have been directly linked with central nervous system disorders created by deficiency states. Of these, only thiamine shows any significant impact on the central nervous system at marginal levels of deficiencies. The central nervous system disorders associated with the other vitamins occur at the very advanced stages of deficiency and as such are only secondary to the individual's overall ability to perform. In the case of thiamine, however, minor degrees of deficiency cause listlessness, apprehension, anorexia and fatigue. These symptoms have been demonstrated within one week after individuals were placed on a thiamine free diet (102). Before leaving the discussions on vitamins, it should be noted that some deficiency effects on other body systems may also alter alertness. For example, night blindness is an early symptom of vitamin A deficiency. Similarly, lesions of the eye are caused by riboflavin deficiency. It is obvious that visual impairment will detract from general alertness.

In the area of mineral metabolism, there are several deficiencies which affect the central nervous system. Animal studies have shown that a severe deficiency of calcium can cause a condition called tetany which is a hyper-irritability of the neuromuscular system. Animal studies also show that a long-term deficiency of potassium will result in a similar condition. Iron deficiency is known to cause acute depression of hemoglobin production and subsequent anemia. Long before anemia is apparent, however, individuals with low serum iron levels become listlessness, feel fatigue and cannot concentrate. Deficiencies of copper in animals have been shown to produce a loss of coordination and behavioral disturbances (103). If allowed to progress, lesions form in the central nervous system and the animal becomes paralyzed. A new element to recognize as a nutrient is zinc. Recent studies in humans show that zinc deficiencies result in both taste and smell impairment (104). In animal studies, zinc has been linked to learning behavior (105). Laboratory animals born from zinc deficient mothers have a decided impairment of learning ability which is overcome with zinc supplementation to the diet. The impact of protein deficiencies on the behavior and learning ability of children are well known. In diets which have insufficient calories to meet the body's needs, protein is used for fuel and part of the observed effects are caused by protein deficiency. Despite adequate calorie intake, inadequate amounts or inferior quality of protein in the diet can also result in impairment of body metabolism. Children who have a simple protein deficiency show a learning disability in addition to retarded growth and other body alterations. In adults where growth is not a factor, behavior changes are still evident with protein deficiency. Individuals are easily fatigued, become listless, and find it difficult to concentrate. Frequently, there is a feeling of hopelessness and aggressive behavior becomes common.

In general, behavioral changes caused by nutrient deficiencies are quite similar. Listlessness, fatigue, an inability to concentrate, and frequently aggressive behavior. All of these conditions would have an impact on alertness. The probability of such nutrient deficiencies occurring, for the most part, seem relatively remote. There appears to be, however, an increase in the incidence of some deficiencies such as iron, and thiamine. Perhaps this apparent increase may be associated with the changing food habits of the population. If so, an increase in incidents can be expected in the future.

Diets with Inappropriate Nutrient Balance

Nutrient balance is both indicated and implied within the Recommended Dietary Allowances established by the National Academy of Sciences of the United States. In terms of the recommendations for energy the levels of fats, proteins, and carbohydrates, which make up nearly all of man's energy intake, have been specified. The impact of unusually high levels of any one of these sources of energy has been discussed as part of the overall rational for establishing the particular level. Diets too high in fat and low in carbohydrate can cause the formation of high levels of ketones in the body. An individuals with this condition, becomes very irritable, restless and easily depressed. Essentially this condition is the same as seen for an individual undergoing short-term nutrient deprivation. Diets abnormally high in simple carbohydrates can in some individuals cause high blood glucose levels. In counteracting this hyperglycemia, hyper-reactive individuals release unusual amounts of insulin and exhibit transient hypoglycemia.

Aside from the need to balance the energy sources in the diet, other nutrients must also be in balance to effect a high level of body productivity. The levels of sodium and potassium should be contained within specified ratios and limits. The lack of compliance will result in the depletion of the lesser cation from the body and thereby cause dramatic effects on the body biochemistry and physiology. Calcium and phosphorus must be within an appropriate balance or depletion of the body stores of the lesser mineral will also occur.

Similar balances are necessary between copper and molybdenum, iron and copper, iron and zinc, zinc and copper and many more (103). Fortunately most food sources throughout the world have an appropriate balance of these minerals. However, imbalances have occurred from indiscriminate addition or removal of these nutrients through processing. In almost every case, the physiological impairment which results will eventually have an effect on alertness. Once again the incidence of occurrence for most of these imbalances appears to be very low. On the other hand, the trend in eating habits of most American male adults has been cited as the cause of early degenerate bone disease. Many male adults have adopted a diet high in animal protein and starch foods while eliminating consumption of green vegetables, fruits and dairy products. Such diets can exceed a calcium to phosphorus ratio in excess of 1:2.5, which has been shown to cause a loss of calcium from the body. This process is slow, but long-term calcium depletion results in reduced bone strength and in some cases bone reabsorption. Nerve damage is frequent when such changes occur in the bones of the vertebrae.

PART IV

Physiologic Aspects

As has been stated earlier, attention is a major component of flying performance. A decrement in attention carries with it more general performance decrement. Fatigue, acute in particular, has a marked effect on attention. Endocrine-metabolic assessments are directed toward fatigue effects in general rather than attention specifically.

The body of knowledge on the physiology of acute skill fatigue has advanced considerably in the past decade. Currently, a basic concept holds that, in persons who have trained to the point of high proficiency on a given operational task, performance decrement tends to be late in onset, apparently having been prevented by means of a complex physiologic adjustment which tends to be early in onset and persistent. This physiologic response involves neuroendocrine as well as metabolic systems. The component responses have received considerable study, but the total (aggregate) response remains to be fully characterized and properly evaluated. Review articles by Teichner (106) and Frankenhaeuser (107) are pertinent, for they deal with behavior-endocrine interrelationships.

Teichner (106), in a review of behavioral/physiologic stress relationships, gives specific consideration to attention. In his analysis, the physiology is focused on the role played by the reticular formation, the limbic system in general and the hypothalamus specifically, in establishing a given level of cortical excitation. The facilitative function of the reticular formation results in a general alerting function. The inhibitory function results in filtering. Together, they result in "cortical tuning", and this tuning includes a state of attention. As activation increases, tuning increases, and selective attention becomes more pronounced up to a point.

On the behavioral side, Teichner puts considerable emphasis on the "band-width" of attention in relation to task complexity, and on the effect of long term memory in interacting with activating mechanisms; these two factors (band width and long term memory) act together at the behavioral level to produce a given state of attention.

Teichner puts the "internal biological world" at some distance from the primary loops described above; we, with our stronger physiologic orientation, would probably show the internal biologic state as a significant component of activating mechanisms inherant in attention.

Frankenheuser (107) reviews the relationship between catecholamines and broadly defined behavioral states. Her review can be divided into effects seen with infused epinephrine and effects with secreted epinephrine. She reports that small doses of epinephrine infused intravenously cause both behavioral arousal (heightened attention) and EEG arousal. Excretion levels are low in subjects at rest or recumbent; under stress, levels can reach 3-5 times the resting level. Epinephrine infusions produce effects described as excited, restless, tense, or fearful. Improved performance is reported with infused epinephrine. There is also a significant increase in epinephrine from both overstimulation (high work) and understimulation (vigilance tasks). However, some studies have shown the greatest increase with the high stimulation situation.

With regard to secreted epinephrine, different subjects show different output. Studies show the output of epinephrine where the arousal level is moderate or low is positively related to efficiency. A rise in epinephrine secretion matches roughly the subjective stress reactions. Subjects who secrete more epinephrine tend to perform better under low and moderate stimulation but more poorly under high stimulation. This supports the well known inverted U hypothesis, which applies to secretion and infusion effects equally. Epinephrine effects are not just the emergency "fight or flight" reaction. It also applies to normal people responding to every day stresses, including both cognitive and emotional.

Barchas, et al., (108) supports Frankenhauser's conclusions regarding epinephrine effects and also review the behavioral effects of norepinephrine. In general, there are no clear-cut effects.

Axelsson (109) presents an extensive review of catecholamine functions. He considers norepinephrine as a neural transmitter. The statement is made that "in their function as natural transmitters of information, the catecholamines may be characterized as either blood-borne or neural transmitters." The same agent may produce different effects depending on whether it is released from the sympathetic nerve endings or reaches the effector by the blood stream.

Davidson and Levine (110) review the effects of the pituitary-adrenal system on behavior. They state that evidence is accumulating which increasingly implicates the pituitary-adrenal system as an important modulator of behavior. Studies have indicated that this system is involved in sensation and perception, habituation, learning, and extinction, as well as aggressive behavior. Cortisol significantly increased isolation-induced aggression in both young and old mice, whereas dexamethasone enhanced isolation-induced aggression in mature animals. ACTH reduced it. In shock-induced aggression there was suppression of ACTH release following fighting when compared with rats that were shocked without fighting. Adrenal responsiveness to ACTH was related to the dominance structure. Although ACTH response levels of individuals remained relatively constant, there was a three to tenfold difference between the lowest response to ACTH (which was in the dominant male) and the highest response (which was in the most subordinate female cagemate). The response levels to ACTH, however, could be altered when the social stress was changed by transferring subdominant animals to individual cages or removing the dominant males. Conversely, removal of the most subordinate cagemate resulted in elevation of ACTH response of the remaining subordinates. Levine reported that more highly aggressive monkeys showed a greater increase in urinary 17-OHCS in response to shock than did the least aggressive ones. It is, of course, conceivable that the pituitary-adrenal system has little or no direct connection with aggressive behavior but may be related only to the level of arousal which is reflected in changes in pituitary-adrenal activity.

DeWied, et al. (111), see especially pages 157-252, chaired a special symposium on pituitary and adrenal effects on behavior. Weijene and Slangen (112) and Bohus (113) showed that ACTH delayed extinction of the avoidance response. ACTH had a similar effect in adrenalectomized animals. The adrenals themselves appeared not to play a significant role in the maintenance of a conditioned avoidance response when the electric shock was no longer present. Many studies have indicated the effects of ACTH and adrenocortical hormones on conditioned behavior. There are clearly demonstrable independent actions of ACTH and steroids on behavior with regard to the extinction of an avoidance response. ACTH can apparently inhibit extinction; glucocorticoids appear to facilitate extinction independent of their action on ACTH secretion. The threshold for the response to inescapable electric shock was subnormal after hypophysectomy. ACTH did not facilitate the acquisition of an avoidance response when the electric shock intensity was high, but it did do so when the shock intensity was moderate. Investigators concluded that the action of ACTH on the acquisition of avoidance conditioning is clearly extra-adrenal, and ACTH is not essential to normal perfor-

nance when the intensity of fear-inducing stimulus is sufficiently high. Glucocorticoids act on several limbic, diencephalic, and mesencephalic regions. Implants of cortisol into the medial thalamus, anterior hypothalamus, rostral septum, or amygdala all facilitated the extinction of a conditioned avoidance response. There now exists much evidence indicating influence of hormones on CNS processes. We are still unable to postulate any specific mechanisms concerning the actions of hormones on the brain.

O'Hanlon (114) reports a study on the relationship between performance on a visual vigilance task and serum epinephrine and norepinephrine concentrations. He ties the ascending reticular activating system (ARAS), cortical arousal, autonomic arousal and vigilance efficiency together. The study showed that vigilance decrement was paralleled by a drop in circulating epinephrine, but not in circulating norepinephrine.

Solberg (115) reviewed the literature on sleep and neuroendocrine mechanisms. The search for an anatomical substrate for the maintenance of consciousness and of various stages of sleep or wakefulness has only revealed more and more complexity. Much interest has been placed on the nucleus reticularis, pontis caudalis, and the basal forebrain. Local application of small amounts of acetylcholine to the medial preoptic region, the interpeduncular nucleus, and the medial midbrain tegmentum elicited sleep, but the same substance produced arousal when applied to the mesencephalic tegmentum. The application of norepinephrine to the medial preoptic region was followed by increasing alertness and by motor hyperactivity. Some authorities claim that there is an adrenergic system in the brainstem responsible for arousal and desynchronization and a cholinergic system for synchronized pattern recorded in deep sleep.

During the past decade the USAF School of Aerospace Medicine has conducted, under either field or laboratory conditions, an extensive series of studies of human responses to flight. The working hypothesis has been that flying operations act in the manner of stressors, eliciting interrelated endocrine-metabolic responses which are compensatory in nature, tending to maintain a state of physiologic balance (homeostasis). A battery of urinary determinations has been used to assess the physiologic cost in a wide variety of circumstances, including flying operations of various types and durations which took place at various times of day and utilized a variety of aircraft. Statistical evaluation consistently indicated elevation in physiologic "cost" which apparently related to type of aircraft, flight complexity, flight duration, time of day, crew position, and anticipatory stress (116,117,118,119,120,121,122).

Hypoxia, one of the more common stressors in aviation, probably has been more throughly studied than any other stressor. The overall response of humans to acute exposure has been fairly well delineated into several specific and non-specific responses. Changes in alertness, arousal, and vigilance are apparent with reasonably minimal degrees of hypoxia. The specific effects of oxygen deprivation include compensation in cardiovascular function (e.g., tachycardia and increased heart stroke volume), respiration (e.g., hyperpnea and hypocapnia), and hormonal change (e.g., decreased release of antidiuretic hormone leading to polyuria). Some secondary responses result from these compensatory changes. One of these is respiratory alkalosis which in turn leads to increased excretion rates of bicarbonate and chloride (which displaces phosphate) ions, and of sodium and particularly potassium ions to neutralize the anions; as a consequence, the urine becomes alkaline. Additionally, there are non-specific responses which are quite widespread, involving neuroendocrine, adrenocortical and metabolic systems. A slight shift toward anaerobic metabolism may occur. The elevated creatine excretion may represent this type of change. Changes in the blood supply to the head lead to decreased visual acuity, decreased performance, and diminished alertness on most tasks, and mood changes. When the high level of sympathetic nervous system activity is overcompensated by the ensuing parasympathetic activation (i.e., the vasovagal syndrome), distress results. This may range in intensity from a simple headache to syncope; but apparently regardless of its severity, one result is a release of antidiuretic hormone. This in turn results in oliguria and a specific decrease in sodium excretion. Superimposed on the specific controlled hypoxia stimulus is the ambiguous emotional one--idiosyncratic, protean, and difficult to control. The latter not only varies in quantity, but more importantly in quality (e.g., the experimental situation may make some individuals anxious, others fearful, others angry, and some apathetic). Likewise, some persons will enter the experiment highly motivated and in an alert state, but others will not be motivated and/or may be lethargic. These emotional concomitants complicate tremendously an experiment designed to elucidate specific effects of a given stressor.

Particularly relevant are the findings of Froberg, et al. (123). These investigators, in a study of circadian variation in psychomotor performance, subjective fatigue, and catecholamine excretion during prolonged sleep deprivation, found that epinephrine excretion was positively correlated with performance and negatively correlated with subjective fatigue and that the reverse relations existed for norepinephrine. When adjustments were made for catecholamine excretion lags, the intercorrelations with performance and with subjective fatigue were even stronger. Frankenhaeuser, et al. (124) found a positive relationship between epinephrine release rate and performance efficiency in situations characterized by monotony and under-stimulation, noting also that objective performance and subjective reactions differed greatly in persons who were differentiated on the basis of epinephrine output. Specifically, high catecholamine output was associated with high performance efficiency.

Corticosteroid measures are another significant part of the USAFSAM battery. In studies conducted in this laboratory (125), in which psychomotor performance was evaluated during 36- or 48-hour simulated flights, subjects who alternately worked and rested at 2-hour intervals showed normal circadian shifting in urinary 17-OHCS for 24 hours, with elevations in 17-OHCS output occurring subsequently. This study showed also that environmental factors intensified the adrenocortical response to the imposed work, but did not adversely affect psychomotor performance itself. The increased adrenocortical activity is, therefore, deemed compensatory, contributing to the maintenance of psychomotor proficiency. In the present study, on the basis of nocturnal values, we found evidence of a progressive decline in epinephrine output and a concomitant progressive gain in 17-OHCS output. Evidently, as bodily reserves at one physiological level tend to decline, an inroad was gradually made on a secondary reserve.

The findings were conclusive, consistently indicating elevated physiologic cost in association with prolonged psychomotor effort and sleep deprivation. The observed responses were complex, each having identifiable (and resolvable) components. The environmental factors under study, when acting singly, exerted modifying influence on one or more of the flight-sensitive physiologic functions: altitude tended to reinforce and dryness tended to counteract responses to simulated flight. In combination, these tended to be mutually

interfering factors, canceling each other's influence either partially or totally. We can only speculate on the functional site or sites at which the dissimilar factors of flight, altitude, and dryness interact. They seemingly act through some final common pathway or mechanism. An unusual type of interaction was observed, that of depression which stemmed from factor combination. In these instances, one of the factors had had stimulatory influence when applied separately. This type interaction, which is reminiscent of occlusion in a reflex arc, has been observed previously in multifactor stress. Grether, et al. (126), found that the combined factors of environmental heat, noise, and vibration tended to be less disturbing physiologically and to have less influence on performance than did certain of the separate factors.

The altitude level used in this study (8,000 ft) is commonly used in pressurized aircraft, but it is not optimal D'Angelo (127) in 10-hour exposures to this pressure altitude, found a variety of psychologic changes (including subjective fatigue which persisted until the next day) along with respiratory alkalosis and hypophosphaturia. McFarland (128) demonstrated memory decrement at this particular pressure altitude. Kallman and Crow (129) found other evidence of impaired mental performance. Pincus and Hoagland (130) reported increases in urinary total 17-KS output.

Sleep deprivation has been shown to affect endocrine and metabolic functions. Fiorica, et al. (131) considered the continued physical activity, rather than the lack of sleep to be instrumental. Scrimshaw, et al. (132) who studied urinary sodium, potassium, and nonprotein nitrogen in relation to sleep loss, noted depression on the first day and elevation on the second day. Rubin, et al. (133) who reviewed the literature on the effects of sleep deprivation on urinary 17-OHCS and 17-KS, mentioned what appeared to be contradictory results in the earlier studies. Later studies, however, showed that there could be a biphasic response, that of an initial decline and a secondary rise. The biphasic response was observed in the present investigation (second ancillary experiment), but it was limited to the model, 17-OHCS. Many of the results observed in the first ancillary experiment may seem bizarre, but these in reality may represent phasic differentiation, with certain of the ketosteroids responding readily to the stressor complexes and advancing to the secondary phase while the less sensitive ones were retarded. Desynchronization of closely related physiologic functions, therefore, seems to be a useful criterion of stress. Internal dissociation of time-dependent physiologic activities is an aspect currently emphasized by chronobiologists.

Knowledge of the 17-ketosteroids response to either simulated or actual flights goes back to 1943, when Pincus and Hoagland (130) discovered that (a) subjects who had the highest performance scores in the final half of 6-hour simulated flights also had the lowest 17-KS outputs, (b) performance decrement was hastened when pressure altitude was merely 5,000 ft, (c) crewmembers of military aircraft (including instructor pilots) showed flight-related increases in total 17-KS output during 4-hour low-altitude flights in unpressurized aircraft and (d) the fatigue level (the rank order of which was established by the Squadron Commander) correlated positively with 17-KS output.

Specific findings in this study deserve emphasis. Certain features of this study merit comment. The study clearly shows that a common cabin altitude (8,000 ft) is not as benign as it appears. There is physiologic cost which relates to altitude, and some of the physiologic effects persist after rest. Also of interest is the finding of "internal dissociation," certain of the physiologic functions gradually undergoing differential phasic shifting. This desynchronization may be a fundamental stress effect, and the variations in phasic changes may account for conflicting reports in the literature. The physiologic instability is indicated by certain of the fundamental stress effects. On the basis of the present data, full recovery appears to require more time than that needed to induce the stress. Multiple stressors may have antagonistic effects leading to partial cancellation of the stress changes in the more sensitive measures; hence we may be underestimating the total potential cost. This may partly explain the relatively long recovery time. Finally, the utility of flight simulation as an effective alternative to field studies is strongly suggested by the data in this study.

Time-zone entrainment and its interaction with flight stress is an area of special interest. Hale, et al. (136) address the problem directly with special analysis of flight stress data. They emphasize long standing stress concepts and principles and to current concepts of neuroendocrine regulation of environmentally influenced physiological functions. Guidance was obtained from reviews of the literature on human circadian rhythms as well as reviews of the literature on flight stress and fatigue. Although circadian variation in psychomotor capability has been well documented, the temporal variability in flight stress responses has not been studied extensively. Our results in general agree with those of Gerritzen et al. (137) who noted concomitant flight stress responses and entrainment effects in men (non-aircrew members) who collected serial urine specimens before, during and after a single prolonged westward flight (Amsterdam to Alaska). Sodium, potassium, the K/Na ratio, urea, 17-ketogenic steroids and V.M.S. (catecholamine end-product) all indicated entrainment-stressor interplay. As in the present case augmented responsiveness appeared early in the flight and again toward the end of the flight (end-spurt phenomenon). Of interest is the finding of a sharp increase in the K/Na quotient which began at 1700 hours and persisted through the period normally used for sleep. There is a concordant finding in the present study for the reciprocal ratio (Na/K) showed a fall. Lafontaine et al. (138) also demonstrated entrainment-stressor interplay during a single, bi-directional transmeridian flight. Their curves for urinary potassium and 17-OHCS deviated from baseline curves, indicating within-day variability in responsiveness to flight stressors. Specifically, as in the present composite flight, potassium indicated slight hypersensitivity at the start of the flight, while 17-OHCS did not. Extensive exploration of the effects of transmeridian flights (which included layover periods of variable duration in unaccustomed time zones) has been accomplished by Klein et al. (139), Wegmann et al. (140), and Bruener et al. (141). These industrious investigators have settled numerous questions about the effects of "time displacements" on fatigue, psychomotor performance, various physiologic functions and various types of tolerance. Particularly pertinent is the report that there is circadian variability in psychologic and physiologic responsiveness to standard stress which appears to relate to adrenocortical responsiveness. Adrenocortical responsiveness, in turn, is traceable (via the anterior pituitary and hypothalmus) to the reticular formation.

Other workers (134,135) have also pursued the relationship between behavioral and physiologic changes. Auffret (142) examined the relationship between subjective fatigue and a number of physiologic measures. Results of a physiological evaluation of the effects of long flights (24 hours) on the crews of DC 7 aircraft specially equipped to receive telemetering transmissions from ballistic missiles and to monitor their landing were as follows. Changes occurred in heart rate, urinary 17-ketosteroids, the urinary mucoproteins, the urinary catecholamines, and glycemia. Subjective impressions of fatigue reported by the crew members are

confirmed by the recorded biological data.

Colquhoun and Goldman (143) examined vigilance under induced hypothermia. The experiment described was stimulated by a study by Wilkinson et al. (144), who found that detection rate in a auditory vigilance task increased as body temperature was raised. In the experiment, the subjects performed for 60 minutes, and the task was a visual rather than an auditory one. Elevation of temperature was achieved by physical work in hot and humid conditions. Results of the experiment, when considered together with those of Wilkinson et al., suggest that it is only when actual body temperature increases that performance in a vigilance task will noticeably alter in hot environmental conditions and, furthermore, the extent of this increase must be considerable before any such alteration occurs.

Puchinskaia (145) examined CNS correlates of readiness (alertness). It is shown that (1) the spoken instruction to be ready for active movement (clenching of the fist) upon imminent command and (2) the preparation of the hand for passive movement by placing a special plate beneath the palm both produce senso-motor-area EEG changes which are analogous to changes produced by the movement itself. The EEG variations correspond by nature and location to proprioceptive influences. Effects of closed and opened eyes during these experiments were also studied. Opening of the eyes stimulated the appearance of the rolandic rhythm. This may be regarded as a result of diminished readiness due to the switching on of visual control. Proprioceptive influences depress both alpha and beta rhythms in the sensorimotor region.

Rahe (146) examined biochemical correlates of behavior in general. He performed a study of subjects in stressful water training. Serum uric acid correlated (high levels with high stress) and with subjective reports on motivation, as well as anticipated stress the day before. Serum cholesterol correlated with load, anticipatory stress, and unpleasant affect scores. Serum cortisol showed no consistent relationships. High individual variability was its primary characteristic.

In summary, extensive investigations of the endocrine-metabolic responses to fatiguing military flying tasks have been conducted in the field and in laboratory studies. Field research has examined the physiologic responses to (a) training and routine flights, (b) flights in single-place or multi-place aircraft, (c) short and long duration flights, (d) westward or eastward or bidirectional transoceanic flights, and (e) westward or eastward global flights, to name only a few. Evidence was consistently found of endocrine-metabolic adjustment before, during, and after flights, but performance decrement was generally not observed. Although there was subjective fatigue in the more prolonged flights, it varied cyclically; and when subjective fatigue was declining, endocrine-metabolic hyperactivity was evident. Laboratory research has provided supporting evidence.

The overall endocrine-metabolic response varies with respect to its character or intensity. In stressful (high load) circumstances the response tends to be widespread, involving the sympatho-adrenomedullary and the hypothalamo-hypophyseal-adrenocortical systems as well as various aspects of metabolism. In low load situations, the response may be limited to the more sensitive components. For each component, it is possible to have gradation in responsiveness. The factor of time of day, for example, alters responsiveness, as, for example, do differences in crewmembers duties (e.g. aircraft commanders tend to be the most responsive members of a crew). Amount of flying experience also contributes to responsiveness. Experience appears to increase sympatho-adrenomedullary responsiveness while reducing adrenocortical responsiveness.

PART V

Environmental Aspects

Because of the increasing demand on crews in military aircraft, attempts have been made to develop environmental design criteria. Webb Associates, in their <u>Bioastronautics Data Book</u> (147), for example, furnish the qualitative and quantitative human data believed to be adequate for designing manned systems. Morgan et al. (148) provide a human engineering guide which the designer can use to assist him in solving design problems as they arise. Woodson and Conover have published a source book (149) designed to help develop equipment from the human operator standpoint, thereby improving the resultant man-machine capabilities. Edholm and Bacharach (150) have compiled the factors affecting the survival of an individual and his ability to adapt to changing conditions. Ashe et al. (151) have presented a historical survey of zones of human comfort and working conditions. Konecci (152) reported the best environmental conditions for extended human performance. Trumbull (153) and Cannon et al. (154) reviewed extensively the effects of environmental conditions on human performance for both short and long-term periods. Burns et al. (155) provided an overview of the research and concepts associated with each of the environmental stresses of space flight.

However, generalizations about the effects of various work environment factors are difficult to offer because of many problems. For example, Dean and McGlothlen (156) suggest that several relatively mild stresses may add up to a total stress far in excess of any one of the single effects. To further complicate matters, Bovard (157) reports that different individuals have different stress thresholds, and that the presence of another human at the time of a stress will increase both individuals' resistance to the stress. Balke (158) agrees with Bovard that man's capacity for stress varies among individuals and within the same individual. Balke further reports that available experimental evidence indicates that the human organism has a great capacity to adapt to exceptional requirements of a biologic nature. Such findings make painfully obvious the difficulty of meaningful generalization. Thus, such people as Thomas (159) voice a strong note of caution in attempting to generalize from existing reports. Thomas examined more than 600 reports on the influence of environmental factors on man's system performance. He indicated that information gaps were so great that any meaningful generalization would be difficult to establish, and that the widely divergent results from apparently comparable stuides ruled against reaching a reasonable overview. Partly with the hope that a more reasonable overview may eventually be possible, the following findings and review of potentially relevant work environment parameters and their relationship to alertness are offered.

<u>Illumination.</u> Webb Associates (147) report that: as the environment becomes darker, objects must be blacker or lighter than their background in order to be seen; at any level of luminance, small objects must have more contrast than large objects in order to be seen; and compensating for any decrease in background

luminance, size of target object, or contrast necessitates an increase in one or both of the other two factors. Morgan et al. (148) and Woodson and Conover (149) provide background information on illumination principles as well as specific lighting recommendations. The developing of a suitable lighting system necessitates considering such factors as: the type of task to be involved; the speed and accuracy with which the task is to be performed; the length of time the task must be continuously performed; and any potential variations in the environmental operating conditions. Glare, insufficient contrast, small size, and uneven lighting of the work space can cause eyestrain and poor performance. Although Aitken (160) reported that some pilots had complained of inadequate cockpit lighting as a source of frustration and fatigue, engineering developments in lighting systems seem to have eliminated most of the illumination problems in aerospace man-machine systems. Despite the occasional aircrew complaints about illumination (as mentioned by Aitken), designers have apparently come close to taking the human-engineering problems of proper illumination out of aerospace systems, since applications-oriented authors, such as Trumbull (153) and Cannon et al. (154), do not list illumination as a problem in discussions of work environments.

Temperature. Woodson and Conover (149) report that moderately complex tasks (such as problem solving and eye-hand coordination) are performed with normal efficiency in temperatures as high as 85° F., however, mental activities, alertness, and eye-hand coordination begin to slow down and the percentage of errors increases. Woodson and Conover report that the optimum work condition is 65° F., and that physical stiffness of man's extremities begins at 50° F. They further report that the more capable and highly motivated persons will be affected more strongly by temperatures above 85° F. or below 50° F. than will the less capable and less motivated persons. Temperatures below 32° F. and above 125° F. become painful for the individual when the period of exposure is sufficiently long. Cannon et al. (154) report that the optimum temperature for working conditions seems to be about 70° F. and that, as conditions vary from this, performance decrement can be expected. Konecci (152) states that the best temperature for extended human performance is 70° F. with an acceptable deviation of ± 10° F. Teichner and Wehrkamp (161) studied visual-motor coordination tasks over a range of from 50° to 100° F., and found decreases in alertness and performance at temperatures both higher and lower than 70° F. Bartlett et al. (162) report that when a man has to carry out a skilled operation and is exposed to heat, he is likely to become less efficient within a few minutes. They further report that the extent of a change in performance resulting from an unusually warm environment is proportionally greater if the crew is working under an additional stress which itself causes a performance decrement. A skilled worker may be able to compensate for an unusually warm temperature (i.e., 90° F.) while performing a routine task, but usually at the expense of some other feature of his job.

Blockley and Lyman (163) trained pilots to fly a series of special simulated patterns. Then the pilots were required to fly these patterns for 61 min. at 160° F., for 29 min. at 200° F., and 21 min. at 235° F. The performance decrement occurred within the last 5 or 6 minutes of these exposures. The younger pilots and the more competent among the older pilots showed lesser amounts of performance decrement; and the more complex tasks deteriorated more than the simple ones.

While these facts indicate reasonably adequate agreement with such factors as optimal working temperatures, many of the complex interactions--particularly over long periods of time--remain unexplained. Temperature effects seem to vary for tasks involving: physical dexterity and eye-hand coordination; perception; the skill level of the operator; and the degree of environmental acclimatization achieved by the operator (164). Kaufman (165) reports that individuals differences in tolerance to thermal stress are great and that further experimentation is required to determine human performance capabilities under thermal stress. Bell and Provins (166) reviewed the literature on the effects of high-temperature environmental conditions on human performance, and concluded that the degree to which difficulty in performing a task results from an uncomfortably warm environment has not been adequately resolved. They also reported that the data covered by their review were insufficient for a completely satisfactory classification of heat effects. Dean and McGlothlen (156) studied individual and interaction effects of altitude, noise, and temperature and concluded that relatively mild stresses may sum up to a total stress far in excess of any one of the single stresses. They warned against the widespread practice of estimating the physiologic effects of the multiple stresses by assuming that, if each of the single effects was in the "safe" region, then the combined effect of the stresses would also lie in the safe region; for a gross underestimation of the multiple stress effect could result. Comprehensive coverages of problems associated with temperature are published by Handler (164), Webb (167), Newburg (168), Burton and Edholm (169), and Winslow (170).

Humidity. The problem of humidity appears to have been slighted in human factors research on the aerospace environmental systems. Woodson and Conover (149), for example, dismiss the problem with the statement that "humidities between 30 and 70 percent have been found comfortable by most people" (--ch. 2, p. 226). Dean and McGlothlen (156) used a one-man multiple-stress chamber capable of simulating altitude from sea level to 65,000 ft., of establishing a chamber temperature from 45° to 400° F., of providing from 70 to 140 dB of white noise, and of providing a relative humidity from zero to 100%. In all their studies of single and multiple effects of environmental stresses, they kept the relative humidity at 50%. Hendler (164) reports two studies on humidity effects--one in which performance decrement proved greater in a warm, moist environment than in a warm, dry environment when both environments had the same effective temperature; and a second study, in which the subject was the effect of high humidity at high and moderate ambient temperature on sustained, complex mental performance. No performance decrement could be found that could be ascribed to the humidity and temperature conditions. Webb Associates (147) report that a change in humidity has little or no effect in extremely dry conditions. Storm et al. (171) reports no performance decrement associated with the very low humidity (less than 5%) typical of the cockpit in flight.

Konecci (152) reports that the best relative humidity level for extended human performance is approximately 35%, plus or minus about 10%. Bartlett (162) reports an experiment by R. D. Pepler that used as subjects some men in England who had been artificially acclimatized to heat and some men who had been living in Singapore. Over a period of 10 years these men participated in experiments designed to measure the effect(s) of high temperature and humidity on various skills. Results of these experiments indicated that: (a) when the effective temperature was held constant, men were less efficient in a humid than in a dry climate; and (b) unacclimatized men were less accurate in following pointers even during their first 10 minutes than were the acclimatized men.

Pressure. Within the earth's atmosphere, the pressure of the atmosphere is a function of the altitude of the individuals above mean sea level; atmospheric pressure determines the amount of oxygen available to the individual during each breath. As altitude increases significantly in a short time (a few hours), the individual will have to inhale a larger quantity of air with each breath, or breathe at a more rapid rate, or increase the percentage of oxygen available in the air than he abstracts each breath--or use a combination of all three methods. Special diets, the use of certain drugs, or other technics may be developed to reduce the quantity of oxygen the individual needs per unit of time. Ample data, empirically verified, on the atmospheric environment best suited for long-term aerospace operations are currently available for use in human-engineering any aerospace system. The absence of atmospheric-associated problems in the NASA space operations, especially in the Apollo flights, is strong verification of the accuracy of the principles currently used to avoid such problems.

Sources concerning the atmospheric environment in aerospace operations and the related problems (such as hypoxia, oxygen toxicity, contaminants, CO_2 and CO pressures, trapped-gas syndromes, etc.) include: Morgan et al. (148), Konecci (152), Trumbull (153), Webb Associates (147), and Woodson and Conover (149). A note of caution, however, is voiced by Lambertsen (172), who indicates that not enough scientific knowledge is available to predict the potential interactions between man's physiologic systems and any extremes of atmospheric factors.

Vibration. Physically and mechanically "vibration" and "noise" are similar because, in each case, the receptors involved are excited by wave motion in the surrounding media (173). Vibrations are "felt" through the somesthetic receptors of the body, while sound is "heard through the ear. Running engines (i.e., automobile or aircraft, reciprocating or jet) are the most common sources of vibrations (148). As with several other areas, enough work has been done in the vibration field to underline its importance as a potential long-term stress factor. Still, as will be shown, more work is very seriously needed, particularly when the concern is with long-term (rather than acute) stress effects of vibration.

In 1959, Forbes (173) reviewed the literature on vibration effects on human performance and concluded that: (a) prolonged exposure to vibration can result in fatigue, irritation, sickness, headache, and even permanent injury; (b) visual acuity lessens under some conditions of vibration; (c) reaction time increases under some conditions of vibration; (d) since vibration is often accompanied by other environmental factors, the effects of vibration by itself have been largely impossible to define clearly; and (e) there have been almost as many experimental conditions as experimenters in the study of vibration effects.

Trumbull (153) reports that depth perception, tracking, visual acuity, and hand reaction are less adequate at 2.5-3.5 c.p.s. Tremor and aiming tasks are influenced below 10 c.p.s., and fatigue can be induced at 4 c.p.s. The fatigue lasts for some time after the task is over, with the degree of fatigue being almost directly proportional to the amplitude of vibration.

In vibration research, according to Hornick (174), general agreement exists that in humans: (a) the amplitude, acceleration increases, and duration of vibration affect compensatory tracking ability; (b) visual acuity suffers in the range of 5-90 c.p.s.; (c) apparently an increase in reaction time follows exposure to vibrations below 20 c.p.s.; (d) psychomotor coordination is affected at specific frequencies; and (e) body equilibrium may be affected after vibration is experienced.

Morgan et al. (148) report that from 1-6 c.p.s. the human body responds primarily to the jolt component of the vibration; from 6-9 c.p.s., to the maximum acceleration; and from 9-250 c.p.s. to the maximum velocity imparted by the vibration. Very low frequency, high-amplitude vibration, acting perpendicular to a horizontal plane passing through the ear openings and the external corners of the eyes, are the primary causes of motion sickness in personnel in automobiles, ships, and aircraft. The range of human resonance is 2-5 c.p.s., and one of the most important factors involving human tolerance to vibration is the thorax-abdomen system. In this system, 3-4 c.p.s. vibration have both longitudinal and transverse directions. Vibration in the transverse direction results in displacement of the abdominal contents and abdominal wall, as well as displacement of the chest wall and diaphragm. Because any operating machine system produces vibrations which have not yet been completely engineered out of the system, research emphasis has been placed on protecting the human against harmful vibrations. Morgan et al. (148) report that the hydraulic shock-absorber system appear to be the most acceptable systems in terms of fatigue effects.

Counterbalanced against these worthwhile findings and conclusions, however, are a number of difficulties. For example, Finkle and Poppen (175) subjected 9 volunteer Navy enlisted men and 1 medical officer to the noise and vibration of a General Electric I-16 turbojet engine for a total of 20 hours within a 6-week period. The subjects were placed in various positions in relation to the engine. Of the 10 subjects, 7 reported increased fatigue and irritability during the entire course of the experiment; but 3 reported no effects of the noise or vibration. According to Coermann et al. (176), experimental results indicate some humans are greatly affected by vibration while other humans are not affected at all. Lippert (177) reports that, while progress has been made in experimentation and in experimental design in vibration research, much remains to be accomplished in studies of effects of vibration on humans. Von Gierke (178) indicates that no criteria for rating vibration exposure are generally accepted, and that all rating schemes are based on subjective judgments of tolerability or comfort and not on objective indications of various levels of physiologic risk. Finally, in the opinion of Weisz et al. (179), vibration research should shift its emphasis from the current physiologically oriented approach to one giving greater weight to the psychologic factors involved.

Noise. As in the case of vibration, much useful work has also been done on noise. So much work remains to be done, particularly with regard to present interests, that many of the current findings are generally interpreted as providing only relevant parameters.

Cannon et al. (154) report that the effects of noise on humans are not always predictable because individuals vary in their sensitivity to noise. Generally, hearing loss occurs as a result of continuous (8 hours or more) exposure to 100 dB (or more) of noise. Part of the loss is regained with rest, but some permanent hearing loss may result. Earplugs or headsets are normally effective protectors against hearing loss for most of the noises to which man is normally subjected. Trumbull (153) indicates that noise (unwanted

auditory stimuli) will not cause the same amount of performance decrement in all humans since there are individual differences in man's susceptibility to noise. When the noise level reaches the 100 dB level, physiologic evidence shows that a greater expenditure of energy is necessary to maintain the same level of concentration as at a lower decibel level. Reactions to excessive noise seem to involve a decrease in attention, accumulation of fatigue, lesser ability to cope with the unexpected or difficult, decrease in some visual functions, changes in physiologic baselines, and temporary or permanent hearing loss. Morgan et al. (148) report that noise, being an undesirable sound, has an irritant or annoyance effect, whose amplitude is proportional to the degree to which the noise distracts the individual from his task. Furthermore, most of the evidence indicates that nonauditory human performance is adversely affected by a noisy environment only in that the noise provides a source of distraction (148). Noise protection that closes or covers the ears only is limited to about 40 dB or 50 dB attenuation before being circumvented by bone conduction. Covering the entire head (helmeted) affords protection against noise up to about 60 dB before body-conducted sound bypasses the head cover. Complete enclosure of the entire body is required to get protection from noise with a decibel rating of 60 dB or higher, the adequacy of the noise-protecting capabilities of the enclosures being dependent upon the adequacy of the soundproofing.

Woodson and Conover (149) report that speech within a noisy background is intelligible when at least 40% of the average speech level is above the spectrum level of the background noise. To achieve noise control, three steps are necessary: (a) select quiet equipment and mount it properly (modify a noisy piece of equipment to eliminate noise); (b) place noisy equipment in a place where the amount of noise is not a problem, and then block the noise off from the area where quiet is important; and (c) use sound-absorbing materials where needed and possible. Bartlett et al. (162) report that noise causes brief failure of attention to work. Such failures will not affect practiced automatic body movements, but will be important only when unexpected stimuli arrive or when a prolonged continuous series of important stimuli occurs and leaves no opportunity for relaxation of attention.

The Federation of American Societies for Experimental Biology (180) states that the noise pain threshold is 140 dB, and that noise levels approaching 140 dB interfere with speech communication. No standards on the level of noise and risk of auditory injury have, however, been accepted by both the medical and the engineering authorities. Gorshkov et al. (181) report an "ultrasound illness" that is one biologic effect of ultrasound. The characteristics of ultrasound illness include frightening dreams at the moment of falling asleep, sensations of weightlessness, short attacks of abulia, loss of appetite, somnambulism, malaise, vertigo, tingling sensations in the mouth, and feeling of unusual fatigue. Harris (182) adds that the rated severity of noise exposure is much affected by the activity in which an individual is engaged when exposed to the noise. Corso (183) points out that large individual differences are generally observed in intellectual performance under high-intensity noise. No personality characteristics, however, have yet been isolated which permit the successful prediction of human performance under noise stress. Von Gierke (178) reports that criteria necessary to judge the severity of impulse are lacking; and although some criteria are available for evaluating the interference of noise with job performance and for judging annoyance with noise, they are not uniformly accepted. As expressed by Shoenberger and Harris (184), perhaps the only conclusion to be reached after reading the reviews of the effects of noise on human performance is that there really are some effects. Largely unresolved remain such questions as whether these noise effects help or hinder performance, how they are related to intensity of the noise, and what changes occur over time.

Ionized air. Chiles et al. (185) found no evidence that the breathing of unipolar levels of ions much higher than those that occur in any normal situation had any effect on attitudes or performances tested, and no effects on complex mental tasks occurred under difference conditions of positive or negative unipolar ions in the air. Frey (186) reported that modifications in human feelings or behavior are not produced by negative air ions and electromagnetic fields, even in concentrations much larger than normally found. Payne (187) found no evidence that exposure to ionizing radiation affected any of the psychomotor skills he used in testing his subjects. Shaefer (188), however, has stated that the high levels of energy output from modern radar and the accompanying, potentially dangerous effects of positive air ions are still to be avoided until more is known about them.

Radiation. While many people are exposed to ionized radiation from various sources (such as household television sets, watches with radiant numbers and hands, or x-ray machines), the amounts of radiation thus received are generally not significant. The major source of traumatic ionizing radiation is the explosion of a nuclear bomb. In such a case, the distance of an individual from the center of the blash and his wind position (upwind, downwind, or to one side) will determine his dose. The larger the dose, the more damaging the radiation would be, the quicker incapacitation would occur, and the less chance he would have of complete recovery. Glass (189), in considering the effect of nuclear radiation on the combat effectiveness of an aircrewman, concluded that a crew would be able to complete a low-level penetration after receiving a dose level of less than 500 R, provided they reached the target within 1 hour, if the exposure dose was 400 R; 1.3 hours, if 300 R; 2 hours, if 200 R; 4 hours, if 100 R; and no limit, if 50 R. An exposure dose of 500 R would make the crew ineffectual. Glass also indicated that the reactions of eleven cancer patients undergoing air doses of 150 R or 200 R showed extraordinary variability in extent and duration. Zellmer (190) reported that individuals receiving 600 R or less were completely effective for performing all tasks for the first hour after exposure; but, by the end of 24 hours, almost all individuals receiving from 500 R to 600 R would require hospitalization; and 50% of those persons receiving from 400 R to 500 R would also require hospitalization. Zellmer also stated that many factors, such as motivation and individual susceptibility, affect the performance of military personnel during wartime, and that these factors would undoubtedly operate during a nuclear war.

Ozone. Young et al. (191) reported that 9 p.p.m. by volume of ozone in the atmosphere will cause pneumonic illness, but that the patients normally recover. In DC-8 aircraft flying between 27,000- and 39,000-foot altitude, ozone was found in a concentration of 0.3–0.4 p.p.m., a concentration that is not significant. Shreuder (192), in studying the medical aspects of commercial jet pilot's fatigue, concluded that ozone was not a meaningful source of pilot fatigue at this time.

Carbon dioxide and carbon monoxide. Woodson and Conover (149) report that: (a) the carbon dioxide content in an enclosed air space should not exceed 0.5%; (b) although a person will not notice a carbon dioxide concentration of 1% or 2% in inspired air, this amount may decrease his proficiency; (c) with more than 3%

carbon dioxide present, he will notice a slight effort in breathing; (d) with 5% to 10% carbon dioxide present, he will breathe heavily and tire quickly; and (e) when subjected to 5% to 10% carbon dioxide for more than a brief period of time, he will die. Trumbull (153) reports that carbon dioxide tolerance in aerospace operations is one variable that cannot be modified or extended through special selection of personnel, acclimatization, training, or other technics. Under present published standards, the maximum concentration of carbon dioxide in an enclosed air space for any sustained operation is 2%. These standards are based on studies indicating that as small an increase as 1% (total of 3% carbon dioxide) can produce deterioration in attention as well as unwanted physiologic and neurologic changes that may linger for some time, although the USAFSAM studies by Welch and his associates do not support this theory. Trumbull (153) further reports that the nervous system does not demonstrate any ability to adapt to carbon dioxide. Morgan et al. (148) state that the carbon dioxide content of an enclosed air space should be kept below 1% when a prolonged, continuous exposure is to be endured. However, subjects have endured a 3% concentration of carbon dioxide for about 6 days without any significant performance decrement (148). Storm and Giannetta (193) found 2 weeks of exposure to 4% CO_2 to have no significant effect on tracking performance or problem-solving ability. Webb Associates (147) report that prolonged exposures of 40 days to air in which the concentration of carbon dioxide was: less than 0.5%, caused no biochemical or other effects; 0.5% to 3.0%, caused adaptive biochemical changes (mild physiologic strains); and above 3.0%, caused pathologic changes in basic physiologic functions.

Morgan et al. (148) report that the carbon monoxide concentration in an enclosed air space should be kept below the 0.003% level for long-term aerospace operations. These standards appear to be excessively severe. However, the same authors point out that as much as 2.5% of the total volume of cigarette smoke and as much as 8.0% of the total volume of cigar smoke can be carbon monoxide, and that the blood of heavy smokers often contains critical amounts of carbon monoxide that can lower their efficiency in, and tolerance for, even moderate altitudes. Webb Associates (147) report that limits for carbon monoxide exposure are from an indefinite period at 0.005% up to 0.08% maximum for Naval aviators and up to 0.6% for Army and Air Force aviators. The threshold limit value (TLV) for industry is 0.01% concentration for 480 min. Headache, dizziness, and nausea are symptoms of both excessive carbon dioxide and carbon monoxide concentrations. Other symptoms of excessive carbon dioxide concentrations are visual problems, respiration problems, and "air hunger" (147).

Other contaminants. In any enclosed air-system supporting aerospace operations, impurities or foreign matters will always be found in the air that are not, in themselves, injurious to health but may affect task performance. Such factors as body odors, food smells (e.g., garlic, onions, etc.), or aromatic tobaccos may be a significant source of strained interpersonal relations (153) or may affect the appetite and lead to poor nutrition (148), thereby causing lowered efficiency.

gardless of difficulties that arise when data from laboratory studies are applied to operational situations, the aerospace systems designers are still not able to engineer out of the system some problems affecting task proficiency. Excessive noise and vibrations, for example, are still part of all aerospace operations; acceleration forces are still potent stressors; and not enough data currently exist concerning the effects of humidity to do more than "strike a happy mean" in attempts to control the humidity effects in long-term aerospace performance.

Altitude and climate. The work environment factors might easily come to mind when one thinks of potential stressors. The altitude-and-climate differences factor and the following general group of factors (such as disease, insects, and plants) are less often thought of immediately, but still appear quite relevant to military problems.

Trumbull (153) reports that the movement of armies by jet transport from temperate to torrid or frigid operational areas in hours, coupled with any diurnal cycle problem, can have a very potent effect on the combat or operational capacity of the individuals. Sudden changes in climate (194) and adverse weather conditions (180), including turbulence (173), are stressors that affect the aircrewmen. Quantified data on the degree to which these factors affect individual capacity or performance are not available. Singly and in combination, however, the adverse weather, the characteristics of the individual, the equipment, and the nature of the mission operate to modify the behavior of the individual (180) in complex ways. Aircrewmen living in a location less than 1,000 ft. above sea level may fly a mission to a location where the altitude is 9,000 ft. above sea level and have to remain there for several days. While the decrease in the partial pressure of oxygen at that altitude may not be severe in itself, its combination with such factors as time-zone problems or sudden changes in temperature-humidity ranges could have a significant effect on the capability of the aircrewmen.

Disease, insects, and plants. Data concerning the effects of infection on human performance have been essentially nonexistent (195), but the U.S. Army has recently sponsored a long-term contract on this problem. Reported results (196) of this program indicate a 25-30% decrement in performance efficiency with an early febrile disease such as tularemia, and a 20-25% decrement with the less severe Sandfly fever. Symptomatic chemotherapy with Azurin and Darvon appeared to obviate the performance decrements associated with Sandfly fever. Behavioral reactions to febrile illnesses appeared more closely related to subjective feelings than to biomedical indices of the illness.

For the typical, healthy aircrewmen, the illnesses which might be considered are not exotic. The well-known "tourist-stomach" syndrome is one result of rapid movement from one geographic culture to another. The acclimatization and immunity built up in one culture may not be effective in another. Even with using extreme care in regard to the food eaten and water ingested, aircrews forced to spend time in different geographic locations and different cultures are exposed to new viruses, bacteria, insects, plants, and levels of satiation. Rapid transition from a hot humid climate to a cold dry climate, and vice versa, can trigger respiratory disorders. Among those factors which probably constitute the best insurance against such incapacitation are: excellent physical condition; extreme care in exposure to foods, water, etc.; and up-to-date immunization shots.

Task Factors

A considerable amount of work has been done in the general area of task factors. The need for caution should be stressed, however, before generalizing from laboratory results in the field situation. There-

fore, the following brief critical review is presented.

Many authors have stressed the difficulty of applying laboratory findings to operational problems. Chapanis (197), for example, points out that we often cannot confirm in real-world situations what the results of laboratory experiments lead us to predict. Dean and McGlothlen (156), as already mentioned, report that any performance estimates based on the available single-stress and single-task research will be essentially meaningless in evaluating multiple-stress e fects on the performance of any specific task by a single individual. Garvey and Taylor (198) feel that man-machine systems, which may differ only slightly in laboratory evaluations, may differ considerably under the exigencies of stressful field operation.

Kibler (199) indicated that the results of classic vigilance research are not particularly applicable to present monitoring tasks. Jerison and Pickett (200) concluded that vigilance research does not contribute meaningfully to the solution of problems of sustained visual monitoring of radar displays either in manned space systems or in any system that is planned for field operation. Dahms and Ferguson (201) report that the accelerative patterns in data from actual flight are so much more complex than those from analytical laboratory investigations that the latter d ta are of limited use in evaluating pilot reactions during severe maneuvers. Bergstrom (202) reported that a human pilot can perform difficult and complex tasks in the laboratory, and the simulator may have excellent face validity; but, when the system is airborne, the pilot's performance deteriorates seriously. Wise (203), as already mentioned, states that the difference between the laboratory and the real work is as great as between man and ape. Westbrook et al. (204) report that many of the psychologists' experiments in studying pilot problems offer so little realism relative to operational conditions that most of their findings have only limited application to practical system design. These cautions, against the casual attempt to use laboratory-developed technics or principles in field or operational systems, apply to many of the following studies of task requirements, work-rest cycles, and task-load problems.

Task requirements. Individuals differ (in all measureable characteristics presently sampled by any psychometric technic) from one situation to another, from one task to another, and in the same task from time to time (148). Any system, therefore, that will require the use of a man in its operation will have to be engineered so that its requirements of man will fall within his basic capabilities plus his inherent variabilities. Morgan et al. (148) and Woodson and Conover (149) agree that certain task requirements should be the function of some machine component-specifically those requirements involving: the storage, recall, and manipulation of large numbers of facts or figures; the application of large amounts of force, quickly and smoothly; operations in environments so stressful as almost to insure human failure; and the almost instantaneous reaction to control signals. They also agree that some task requirements should be the function of the human operator, especially tasks involving: the discrimination of signals in noise; the perceiving of patterns in changing fields; the improvising and use of flexible procedures; and the use of originality in solving problems.

Factors antagonistic to short- or long-term efficiency include: increasing the speed with which a display is presented, or increasing the number of displays to be monitored (205); working in the same position for a long period of time (148); excessive administrative requirements (160); man-machine incompatibility (148); and overloading the operator (206). Again, however, a major problem in establishing man's functions in an operational aerospace system lies in the fact that the majority of data pertaining to man's capabilities in a man-machine system come from laboratory studies.

Task load. The problem of task loading seems to have been largely human-engineered out of the present aerospace systems--insofar as the actual operation of air-transport system is concerned. For example, Billings and Eggspuehler (207) point out that, in studying changes in selected variables though to be caused by fatigue and task loading, they found that the differences between subjects was much larger than any differences in output presumed to be caused by fatigue or task loading. Stanbridge (208) reported that in the results obtained by questioning 391 aircrewmen who flew 14,000,000 miles in 100,000 sorties to deliver 1,000,000 tons of freight during the Berlin Airlift, no aircrewmen was reported to have given task overloading as a significant source of frustration or fatigue. Shreuder (192), in the medical aspects of commercial jet-pilot fatigue, did not list task loading as a significant factor. In investigating the pilots; workload in civil airlines, Smith (209) reported that, in the operational setting, the major source of frustration was the inability to adhere to the schedule; task load was not listed as a significant factor. In applying time and workload analysis technics to transport pilots, Cantrell and Hartman (210) found that neither the task load nor the flying hours required were the major sources of frustration to these pilots, but rather such factors as lack of planned free time, excessive ramp-pounding time, and avoidable enroute delays. Aitken (160), in reporting the results of an interview study of aircrewmen, did not find that task load was a significant source of concern to the pilots.

Task loading was not found to be a direct cause of aircraft accidents by either Hartman and Cantrell (211) or Goorney (212). Hartman and Cantrell, however, indicated that, because piloting was more demanding on the approach and landing phases of flight than in the cruising phase, changes in task loading could be a factor in landing-short accidents. Westbrook et al. (204) emphasize the need for a reliable measuring of aircrew workload or stress. Hartman and Cantrell (213) point out that the ultimate goal of biomedical research is the maintenance of man's capacity for skillful work, and that problems of human efficiency associated with physiologic degradation disappear when the physiologic problem is engineered out of the system. Fitts (214) reports that one of the best ways of increasing the probability of reliable performance under unfavorable environmental conditions is to insure that all aircrew responses potentially required during operational use of the system are within the aircrew's highly overlearned habit system.

Acceleration. Acceleration is included here because it is an integral part of taking off or landing in an aerospace system, or of making a relatively rapid change in speed or direction while moving at a relatively rapid speed. Morgan et al. (148) call the acceleration vector in a plane parallel to the body's longitudinal axis: positive acceleration, if it is in the head-to-foot direction; and negative, in the foot-to-head direction. The acceleration vector in a plane perpendicular to the longitudinal axis of the body is called transverse acceleration. Linear acceleration is that in which the position of the longitudinal axis changes in a straight line. Radial or centrifugal acceleration occurs when the longitudinal axis is rotated around a central point so that its velocity vector is constantly changing direction. Angular

acceleration is produced for the same condition when the velocity vector changes magnitude and direction.

Woodson and Conover (149) and Clarke et al. (215) report that a subject's tolerance to acceleration is increased by placing him so that these forces are transverse to the long axis of his body, and by the use of positive pressure-breathing by the subject. They state that auditory rather than visual signals should be used when critical acceleration levels are anticipated, and that armrests and controls should be placed close to the operating position if they are to be manipulated during periods of extreme forces. In a rotating space station, the Coriolis (or centrifugal) force would add another dimension to the problem of the occupants of the space station. Overcoming deleterious effects of the Coriolis force would involve: (a) placing any consoles perpendicular to this force so that lateral hand movements would not be disturbed; (b) positioning tall racks or files so that the pulling out of drawers or racks would not be affected by the force; (c) positioning any ladders so that the Coriolis force would not throw a man either away from or against the ladder; and (d) sleeping in bunks with the foot toward the direction of the rotation, so that the Coriolis force would help the individual raise up out of bed. The report by Webb Associates (147) furnishes considerable data pertaining to the various acceleration factors. These data are markedly enhanced by the highly successful space flights, managed by NASA, in which these data were used to establish the man-machine parameters. Following are some of the general principles developed: (a) Acceleration stress significantly impairs visual capabilities (under conditions of increasing acceleration, visual acuity decreases, stronger illumination is required, but less brightness contrast is needed). (b) Strong individual differences exist among pilots in resisting performance decrement during exposure to high G. (c) Some pilots, during or after acceleration exposure, are subject to false perceptions of their position and motion (pilot performance proficiency can be markedly improved during exposure to high G through acceleration training programs). (d) The proficiency of a pilot performing under high G is significantly affected by the characteristics of the control device used. (e) The measurement of a pilot's performance capabilities is affected by the instrument-display characteristics. (f) Tasks performed easily under low G conditions become more difficult as G increases. (g) High G affects intellectual skills, concentration, time perception, judgment, and immediate memory. (h) The direct effects of acceleration may lead to a lesser psychophysiologic impairment of the pilot than do the emotional reactions generated by the anticipation of acceleration. (i) Acceleration stress may combine with other environmental stresses in modifying the performance of the pilot.

Trumbull (153) reports that all studies of tolerance to acceleration forces show the usual individual differences, thus suggesting that selection of pilots for acceleration tolerance might play an important role in aerospace operations. Many subjects have been repeatedly exposed to various levels of acceleration by numerous experimenters, with mixed results. Some researchers report adaptation to acceleration forces, and others report decreased tolerance to acceleration forces. Chambers (216) states that flying an airplane exposes the human to potentially severe acceleration forces, to which "grayout," and vertigo are well-known reactions.

The effects of acceleration on task performance appear to be related to task complexity and difficulty, and to mechanical interference. Large individual differences in emotional reactions to acceleration forces have also been observed. Euphoria, fear, tension, and nausea are some of the observed "personality" effects of acceleration. More data will be needed in order for the relations between acceleration forces and continued pilot competency to be understood adequately. Sem-Jacobsen (217) used an 8-channel airforce EEG to record the brain waves of 30 different pilots while they flew 65 missions. Rolls, dives, and the pulling of 6 G's were included in each flight. He found marked individual differences in the EEG reactions of the 30 pilots to the various mission stresses. The study showed that some active duty pilots undoubtedly experience some unconsciousness and sometimes convulsions while flying fighter aircraft through extreme maneuvers.

Stress tolerance. In the most general sense, stress is inferred when some factor (stressor) causes dehabilitation in any of the psychologic or physiologic functions of man. The force of the stress is directly related to the magnitude of the deviation. The Joint Discussion Forum on Behavioral Sciences (218) emphasizes the needs of the armed services for increased knowledge of the long-term and interactional effects of all stressors. Agrell (219) reports that a primary task of military psychology is to find out more about behavioral changes under stress. Not only do people react differently to stress, but the same individual will have different reactions to stress-depending on the type of stressor affecting him. Selye (220,221) has provided a model for the effects of stresses on human behavior and adapted functions—an approach that has received wide acceptance by behavioral scientists. Stresses can be severe for a short time or minimal for a longer period of time; both aspects should be considered. Stress can be either physical or psychologic or any combination of both. Nayenko and Ovchinnikova (222) state that psychic stress develops in man in different stiuations, during mental and emotional overload, when something interferes with his task performance, or through personal failure in his work.

Collapse under stress is hard to predict. Gerathewohl (223), for example, reports that men who had been identified as prone to breakdown under stressful situations nevertheless served long and well, even on tours of combat. Dynes (224) states that only about 5% of men who served in combat had a breakdown as a result of stress. Dynes further reports that the evidence, obtained from men fresh from combat and from survivors from sunken ships, does not support the widely accepted theory that all men have psychologic breaking points. In describing the stresses of combat on Guadalcanal, Lidz (225) reported that the man who did not "crack up" from stress had experienced one hazard after another, suffered the same frustrations, fought the same battles, and experienced the same hardships and disappointments as those among their peers who did crack up.

Civilain disasters are sources of data on the immobilizing effects of acute stress. In reporting on the community reactions to the stresses of a disaster, Tyhurst (226) stated that less than 25% of the persons involved were capable of performing the constructive activiites necessary to mitigate the effects of the disaster, while the other 75% exhibited behavior ranging from bewilderment to paralyzing anxiety and hysterical fear.

Klein et al. (227) state that the magnitude of the stress on a flight crew is determined by the intensity of the stressing factors and by their duration and frequency of occurrence. Boyles (228) points out that the normal stresses inherent in flying may interact with the stresses of combat and aggravate them.

Frykholm (229) reports that ope. "io" ^l aircrewmen undergo the most careful medical and psychologic screening and selection and are consta ,jected to regular medical checks. Throughout their careers, the operational aircrewmen are also ..cantly subjected to high stressor loads during all types of flying missions. The highly motivated aircrewman may manage the stresses of flying with suitable anxiety-handling mechanisms; but some aircrewmen apparently do not have the psychologic resources to manage stress and are, through various mechanisms, removed from flight status. Some of the stressors that face the operational aircrewmen are: family troubles; reduction in job satisfaction; transfer to a higher performance aircraft (229); emotional stress (230,212); fear of failure (231); any anxiety, no matter what the source (180); and fear of personal risk (219). Trumbull (153) reports that the quality and/or quantity of stress can be altered by the state of the mind, anticipation, familiarization, and training. Fine and Hartman (232) describe personality factors which influence stress tolerance. Shriver (233) reports that chronologic age does not appear to contribute significantly to differences in performance under stress. Goorney (212) states that emotional stress may be a significant contributor to pilot-error accidents.

Haward (194) reports that respiration is the single best measure of stress, with galvanic skin response (GSR) and pulse rate being the most compatible variables with respiration to indicate level of stress. (Many physiologists would not, however, agree with this probably oversimplified statement.) Consideration of the stress problem at the Kennedy Space Center (234) led to the conclusion that, from individual to individual, great variation exists in total available energy reserves, the rate of energy transformation necessary for the body to cope with various stresses, and the rate of rebuilding energy reserves. Considerable variation also appears to occur in rapidity of response to stress, onset of fatigue, and the levels of daily stress necessary to produce accumulate or chronic fatigue. Individual differences in reactions to stress are likewise reported by Agrell (219), Balke (158), Bergstrom (202), Coermann et al. (176), Curran and Wherry (235), Lidz (225), Nayenko and Ovchinnikova (222), Shriver (233), and Wherry and Curran (236).

There seems to be no reason to doubt that, with the appropriate devices and technics, aircrewmen could be selected who would be highly resistant to major stressors. (Substantial progress toward this goal was shown by the work of Sells, particularly in the emotional and motivation sphere; but the program was terminated before the goal was reached.) Wilson (237) reports that, for selection of Project Mercury candidates, psychologic stability (resistance to change under stress) was the most important factor in the evaluation, with physiologic performance being a secondary consideration. Flinn et al. (238) state that, in considering candidates for future space pilots, the ability to tolerate stress and frustration without significant emotional symptomatology or impaired performance is considered to be an important personality characteristic. Bovard (157) reports that the presence of another human at the time of a stress increases both individuals' resistance to stress.

PART VI

Crew Performance and Fatigue

The workloads and task demands imposed upon air crewmembers in modern military aircraft are substantial. The missions have become more demanding and crew effectiveness and alertness are clearly quite high on any scale of "criticality." Further more, many mission durations, nominal and contingency, are significantly longer than in the past. The requirements for work prior to the flying segment of a tour of duty further complicate the problem. Because of these considerations, it is appropriate to put more emphasis on hardware and software factors impinging on crew performance than has been done in the past. The material which follows is a brief summary of existing knowledge on crew performance.

Psychologic Effects of Physiologic Stress

An important area of concern is the evaluation of performance impairment produced by physiologic stressors known or suspected to exist in an operational system. Within the limited space available here, it appears best to deal with the problem of psychologic effects arising from physiologic stress in summary form. One such summary is presented in the form of a qualitative table. Shown are the effects of 12 stressors on 20 aspects of performance selected for their pertinence to crew functioning.

In general, low levels of biodynamic stressors such as acceleration and vibration alter crew performance because they "load" the limbs and interfere with coordination. Low levels of other stressors like hypoxia compromise crew performance by inducing a generalized fatigue and/or CNS insult. Any stressor producing unpleasant subjective states and bodily discomfort or physiologic compromise distracts an aircrewman and reduces his alertness. Such distractions create a situation in which a substantial possibility of poor performance exists. At the higher levels of physiologic stress, or following prolonged exposure to moderate levels, physiologic compromise is usually sufficient to become the significant problem, and to outweigh performance aspects as the focus of concern.

TABLE 1

PSYCHOLOGIC EFFECTS FROM PHYSIOLOGIC STRESS*

Psychologic effect	STRESSOR																			
	90% hypoxia	Arterial saturation		Atmospheric contaminants	Thermal		Water loss	Smoking	Alcohol	Barotrauma	Hypoglycemia	Radiation		Acceleration†					Vibration	
		35%	80%		Cold	Heat						Low	LD_{50}	Neg. G	Zero G	Up to 3/G	3.5–5 G	Above 5 G	1–10 cps	1-15 cps
Motivation				+	+	+	+		P	+	+									
Distractions due to:																				
Pain, etc.				+						++				+			+	++	P	+
Irritability, etc.		→	→	P		+	+	P	+			+	+						+	
Discomfort	+	+	++	+	+	+				+	+			+			+	++	+	+
Fatigue	+	+	++	+	+	+	+	+	P		+	+	++						+	+
Subjective cost of work		+	++	+		+	+	+	+				P	P			P	+		
Activity level			+		+	+			+	+		P	+	+						
Vigilance alertness		P	+	+	+	+			++		+			+		P	+	+		
Span of attention		+	+						+	+	+		+						P	P
Sensory	P	+	++	+				P						+	P	P	+	++	+	+
Perceptual			+						+						+					
Motor•																				
Simple			+		+												+	++		
Complex		+	++	+	+	+			+		P			+		P	+	++		
Discrete			+														+	++		
Continuous		+	++	P	+	+			+					+		P	+	++		
Neuromuscular co-ordination		+	++	+	P				++	+	P			+			+	++	+	+
Arthmetic, etc.		P	+						P											
Reasoning		+	++						++		P		P					+		
Judgment		+	++	P					++									+		
Memory		+	++	P					+									+		

* P = possible decrement, + - measureable decrement, and ++ = substantial decrement
† Effects at low levels are largely mechanical-limbs are "loaded."
• The well known euphoria associated with hypoxia has not been entered in the table.

Psychologic Factors

The previous section focused upon the influence of extrinsic factors upon the efficiency of man. The emphasis was on mechanical effects and physiologic insult; in those areas, alterations in performance were considered to be second order effects. This section will consider intrinsic factors, in many cases involving mechanisms resistant to definition. The importance of these factors is, however, reinforced by the criticality of <u>any</u> decline in the efficiency of the crew. It is important to remember that performance can degrade even when the environmental situation has been optimized.

Fatigue

The problem of crew fatigue has been with us for a long time. It defies rigorous definition. The list of effects is long. The significant aspect, from the weapons systems point of view, is that performance becomes poorer during an extended period of work. Subjective changes also occur in a systematic fashion. These are usually of secondary concern when one is dealing with acute fatigue, except as subjective fatigue levels provide an additional index of the general physical status of crewmembers. Only a small part of the literature on acute fatigue is applicable specifically to crew efficiency. In the pilot domain, certain psychomotor changes are generally believed to occur. Evidence has been obtained that acute fatigue effects are related fundamentally to momentary lapses described as "blocks." As fatigue accumulates, these lapses become more frequent so that overall efficiency is lowered. It appears that these blocks represent a complete cessation of psychologic function and that the performance of the fatigued flier is largely one of normal levels of efficiency with interspersed blocks. This probably accounts for the confusing results when one asks an aircrewman to report on his own level of performance. He observes that <u>most</u> of his performance is reasonably good, and he is inclined to minimize the lapses, particularly if they are not too frequent. Therefore, he reports that he is "doing fine," to the surprise of an outside observer, who is impressed by the lapses. On the other hand, if asked to report on his own state of fatigue, he is likely to say "tired," which agrees with the observer's estimate.

There are also differential fatigue effects in different classes of tasks. Tasks based on gross, discrete cues are more resistant to fatigue than tasks based on minute cues, in which vigilance and alertness are important. Vigilance and alertness appears to be the function most affected by acute fatigue. For the more complex and prolonged tasks, it appears that proficiency cannot be maintained at acceptable levels

much beyond 20 hours without rest. Some tasks particularly susceptible to fatigue may have a shorter period of maximum performance.

Flying high performance aircraft places demands upon mental application and acumen of the pilot. Brief lapses in attention, dilution of alertness, may produce an accident-prone situation. Fatigue, by definition, signifies a decrease or detrimental alteration in performance due to the duration or repetition of an activity, aggravated by physical, physiological and psychic stresses. Flying fatigue is implicated as a contributory factor in various "pilot" error accidents.

(a) Fatigue increases proneness for disorientation.

(b) Fatigue reduces attentive visual scanning, increasing chances for mid-air collisions, and for misreading charts.

(c) Fatigue lowers judgment and attentiveness, possibly contributing in loss of control at low altitude, approach and landing.

Flying fatigue is a combination of physical, physiological and psychological factors. Fatigue is defined differently by different disciplines. It is next to impossible to measure all of its components in the flying situation, through psychological and hormonal stress tests postflight indicate its presence. Fatigue in flying falls into two overlapping and interdependent operational categories.

(a) Chronic Fatigue.

(b) Acute single mission skill fatigue.

Chronic fatigue occurs when physical, mental and social recuperation between repeated missions is incomplete. It can rapidly occur in any repetitive maximum effort mission unless preventative measures are instituted. The RAF in the Berlin Airlift reported a 90 percent incidence of fatigue symptoms. Some of these symptoms were: Flight Surgeons noted tiredness, apprehension, increased drinking, weight loss, bickering, and multiple minor physical complaints. Commanders noted that landings were bumpier, taxiing careless, controls were handled more clumsily and flight planning was sloppy. Crews felt much of the difficulty rested with lack of sleep, waiting between flights, poor living conditions and unsatisfactory ground organizations, coupled with long working hours and in-flight factors, such as aircraft comfort, etc. When steps were made to improve living and sleeping conditions, to provide definite off-duty time, etc, fatigue markedly lessened.

A variety of factors contribute to chronic fatigue. These include:

(a) Length of flights, false starts, delayed flights, waiting periods at intermediate stops.

(b) Poor layover facilities, bad beds, poor sleeping conditions, bad messing facilities, lack of recreation and diversion, irregular or missed meals, bad ground station organization.

(c) Reliability of radio aids, particularly in the Arctic and around the border of USSR.

(d) Uncomfortable personal equipment - oxygen masks (pressure suits).

(e) Weather, anticipation of bad weather, rough flying with auxilliary crew on the verge of airsickness.

(f) Physical condition, lack of exercise and general body tone, poor eating habits in general, drinking the night before flying and during intermediate stop, smoking in relation to altitude tolerance and blood carbon monoxide-hemoglobin levels.

(g) Aircraft design "human factors engineering," seat comfort, flight deck design, facilities for sleeping in the air, working area lighting, reliability of the "bird" and confidence, adequacy of heating and ventilating systems for arctic and tropical flights, facilities for good in-flight meals, noise and vibration levels, instrument arrangements.

(h) Toxic factors such as prolonged flying at 10,000 feet and slightly over without supplemental oxygen, as well as carbon monoxide and carbon dioxide in the cabin.

(i) Leadership and team spirit, relations with aircraft commanders, relations with superiors on the ground, adequacy of support and backup, amount of paperwork, satisfaction with organization, amount of responsibility of the individual.

(j) Personal factors, amount of flying experience (earlier flights in a career tend to be more fatiguing), domestic difficulties, financial security, personality of the individual, motivation and conscientiousness.

(k) Breaking of the normal diurnal rhythm (the day-night cycle).

(l) Unforeseen inflight emergencies.

Acute single mission skill fatigue is recoverable with a good night's rest. Skill fatigue has become more of a problem with increased cockpit hours. The factors are primarily psychological and include monotony, continued attention and responsibility, immobility, apprehension and boredom. However, physical factors, such as generally poor physical condition, accelerate fatigue. Lack of attention to physiological disturbances such as mild hypoxia, hypoglycemia, poor diet, alcoholic intake, blood carbon monoxide from oversmoking, all greatly increase fatigability. Flight factors such as weather, mission difficulty, cockpit and equipment comfort, noise, feeding facilities, heating systems, length of flight and radio reliability all play a fatigue-producing role.

Skill fatigue is characterized by:

(a) The requirement for larger than normal stimuli for evocation of appropriate responses.

(b) Errors in timing.

(c) Overlooking of important elements in a task series.

(d) Loss of accuracy and smoothness of control column and rudder movements.

(e) Unawareness of the accumulation of rather large errors in azimuth, elevation and attitude.

(f) An increase in control movements involving greater fluctuation in order to produce the same effect.

(g) Under and over-control movements.

(h) Forgetting of side-tasks.

(i) Increasing unreliability of reports of what transpired.

(j) Errors of inattention. Failure to scan sky, fixed vision.

(k) Preoccupation with one task component to exclusion of others.

(l) Allowing various elements of operational sequence to appear out of place with respect to one another.

(m) Easy distraction by minor discomforts, aches, pains, noises, etc.

(n) Increasing unawareness of performance deficiencies, and in extremes, usually involving intemperate RON's and TDY's, signs of physical breakdown such as fainting, cardiac arrhythmias, etc.

The RAF found in one study (20d) that fatigue occurred after 10 hours in piston aircraft, was greater at night, progressed in severity during four 15-hour night missions, was objectively (not subjectively) present after three sorties of one hour in jet fighters, fatigue response varied greatly among pilots, there were performance spurts for landings and emergencies.

One can see that chronic and acute fatigue overlap. Tough single missions if close together can predispose to chronic fatigue. The individual who begins flight in a fatigued condition will develop acute skill fatigue earlier and more severely.

The attack to eliminate fatigue is multipronged. Aircraft design and personal equipment are engineered toward decreasing fatigue factors and producing increased comfort. Modern mission planning, such as the extensive efforts of SAC includes preventative consideration of in-flight and between-flight fatigue components. Continuing excellence of support in such areas as:

(a) Good maintenance - effective pressurization, reduction of noise, decreased failures of equipment inflight.

(b) Good facilities - flight lunches, transit transportation, transit messes, VOQ accommodations, air-conditioning, showers, etc.

(c) Good equipment - oxygen masks, personal equipment, runways, etc.

(d) Good service - alert tower operators, attentive dispatch and weather personnel, a good program of medical support from an interested teaching flight surgeon and PTO.

(e) Good leadership - high morale, high motivation, awareness of the mission, support for problems, duty schedules known in advance to allow for planned rest and minimum wasted time.

However, the cornerstone of any fatigue-reducing program is the aircrewman, himself. He must keep himself in good physical condition and not flaunt preflight and in-flight physiological requirements. These include:

(a) A program of suitable exercise.

(b) Oxygen discipline.

(c) Regular meals to prevent hypoglycemia, flight lunches.

(d) Prevent dehydration.

(e) Keep alcoholic intake before flight to a minimum.

(f) Realize that excessive smoking produces 8-10 percent carbon monoxide-hemoblobin.

(g) Should control psychological and emotional problems such as family problems and anxieties, which should be left on the ground, and over-partying which only wears the body down and depletes one's resistance to psychic stress.

There is increasing emphasis on self-discipline in the aircrewmember. He should arrive at the aircraft in the best possible condition. During flight he should maintain rigid anti-fatigue discipline.

(a) Keep a rotation schedule.

(b) Let the copilot fly.

(c) Keep hydrated.

(d) Eat regularly.

(e) Stretch the muscles.

(f) Maintain oxygen discipline.

(g) Move about if possible.

Duty schedules containing programmed periods of rest, on the other hand, can be carried out quite effectively for many hours. Also acute fatigue, and indeed, general performance problems are complicated by aging; performance degrades in a non-linear fashion with age. For example, typical reaction time in a 60 year old are double those of the 40 year old pilot. However, neuromuscular losses due to aging are probably offset by more efficient or better organized approaches to tasks. One factor important in fatigue is the physical inactivity resulting from confinement to an immediate work area, the relative vagotonia which may result includes subjective states much like those associated with fatigue, though there is at this time no direct evidence relating a mild vagotonia to impaired performance.

As indicated earlier, it is conventional to think of two classes of fatigue, acute and chronic. It appears fruitful to add a category midway between the two, cumulative fatigue. Cumulative fatigue is the result of inadequate recovery from several successive periods of acute fatigue or from several periods of inadequate sleep, and appears gradually over several days or weeks. Performance effects are like those seen in acute fatigue, including poorer performance and degraded management and judgment. The subjective aspects assume greater importance. Meaningful impairment in motivation, emotional control and interpersonal relationships can develop. Situational factors play an important role in the buildup of cumulative fatigue, particularly the marginal aspects of crew support functions, crew rest facilities, schedules, and round-the-clock operations. Among the more common place subjective effects are increases in bodily complaints, particularly increased tension symptoms, frequent complaints of excessive fatigue, and so forth. Personal factors such as age, experience, skill, motivation, freedom from personal concerns, and personality structure operate strongly in maintaining resistance to cumulative fatigue.

Chronic fatigue, in the special sense in which it is used in medicine, is rarely seen in crewmen. Where it occurs, it appears to be the classic psychoneurotic maladjustment to situational stress, and is best handled clinically without reference to work factors or related aspects of the psychology of human efficiency, per se.

Diurnal Effects

Diurnal variation is another factor involved in prolonged work. Shifts in proficiency of a general order of ± 8% have been reported. The largest losses in efficiency are generally found where operators have already been on duty for some time (i.e., where the psychological reserves are already somewhat depleted) or where task demands are such there is a propensity for performance degradation. For example, losses in proficiency have been demonstrated in relatively inactive tasks; these losses are greater in the early morning hours. However, more "active" tasks may show no such loss, even when they occur during the same early morning hours. These findings have been interpreted as indicating that diurnal stress is a secondary performance factor. If performance decrement is already present, it is increased by the requirement to continue working through the early morning hours. If the operator's performance is at normal levels and other primary stressors such as fatigue are not taking their toll, no significant diurnal effects are likely. One important situational aspect of the mission work schedule needs to be kept in mind. Morning flights, with the unavoidable requirement to get up early in order to complete predeparture preparations, may well involve a significant loss in sleep, which sets the stage for inflight fatigue problems.

Work/Rest Schedules

The manning problems of the more complex aerospace systems has led renewed interest in optimal work/rest schedules. Some investigations of this problem have occurred in simulated space flight studies, where the work/rest routine is under careful control. It appears that the important factor is the maximum time on duty. Duty schedules should not require continuous work to the point where significant fatigue effects occur, or interfere with rest and recovery between shifts. Within these limits, many schedules are feasible; factors such as the flight profile, schedule requirements, and crew size become more important.

The problem is how to arrange the duty day to provide sleep periods, rest periods, and still provide continuous coverage throughout a day, for perhaps several days in succession. Laboratory studies have demonstrated that man can perform acceptably on schedules as unusual as 4 hours on duty/2 off or even 2/2, but the sleep schedule which goes with this does not permit adequate recovery. The crewman's physical reserves are reduced, and his capacity to handle some emergency condition such as a requirement to work continuously for many hours in an emergency is seriously compromised. Schedules permitting six or more hours in a block for sleep and rest are significantly better for maintaining reserves needed during prolonged emergencies. Questions regarding what constitutes adequate sleep are central to the problem, not only in terms of total quantity but also the daily requirements for various stages of sleep. The compounding of partial sleep deprivation by environmental stressors is also an area of concern.

Improved formulations of the psychologic problems in advanced aircraft will emerge from better definition of mission tasks to be performed. A major activity should be human engineering of work stations and crew facilities. Another major area is time-line and work-load analyses of major mission tasks. Background work should consist of studies directed at work/rest schedules, and at the relationship between work, fatigue, and sleep in settings which provide reasonable simulation of the inflight environment and mission tasks. The capability for much of the study effort described here is available inhouse, providing the schedule is matched to manpower resources.

Performance Upon Awakening

Another potential problem is that of crew performance upon sudden awakening, as occurs to crews sleeping during a prolonged "alert." Laboratory studies have shown a decrement of 25% for the first minute after awakening, in comparison to normal daytime efficiency. The recovery curve appears to be linear for simple, discrete tasks, though full return to normal levels may not be achieved for as long as 20 minutes or so. More complex tasks require a longer recovery time. The use of klaxons or similar alarms does not seem to facilitate performance, but a very few minutes of non-working time where the crewman can devote himself exclusively to waking up offsets the decrement. Apparently, having to work in a concentrated fashion after sudden awakening interferes with the capacity to perform effectively. Crewmen who have had to face this problem repeatedly probably do not show as much decrement, because experience and training are always major levelers of impairment resulting from psychologic stress.

The Metabolic Clock Problem

The behavioral effects of flying through time zones has been studied largely on commercial passengers. Some gross behavioral disruptions, including increases in reaction time and subjective changes, have been demonstrated, but the problem has not been evaluated in depth. Speculations about differences due to flying east versus flying west have not been studied adequately. So far as can be determined at this time, the stressors are situational--a man finds himself out of step with the local environment and therefore compromises his own schedule in critical functions like eating, sleeping, etc. Performance decrement occurs in response to these compromises and is only indirectly the result of flying through time zones, per se.

Alterations in States of Awareness

Reduced awareness is another area where the probability of crew stress is low, but the possibility exists. Increasing attention is being given to alterations in man's prception of his surroundings under environmental and physiologic conditions which apparently are within normal limits. In some respects, both flight and mission crews are more susceptible than the typical man on the ground. The effects are best characterized as undue narrowing of attention, inability to properly focus attention, or actual distortions of sensory input. In many cases, these experiences, such as the sense of detachment described as the break-off phenomenon, appear to be innocuous, but the possibility of significant degradation in performance exists. These states are based primarily upon psychologic factors although concomitant physiologic mechanisms may account for an elaboration of the condition (e.g., hyperventilation secondary to anxiety, or drowsiness associated with a monotonous environment). This phenomenon can be viewed as a disorder of information processing, related to an input either above or below the optimum range for processing, or to conditions in which the flier is unable to deal adequately with the relevant input.

These kinds of effects related to task load may be seen. When sensory input is below the optimum, inattentiveness or boredom occurs, leading to lowered proficiency. In certain situations of sensory impoverishment, a more marked change occurs in the individual's subjective perception of himself and his environment. He may, for example, feel that he is no longer in control of himself, but is an "outside observer" who would be unable to respond appropriately if required to act. Depersonalization and unreality feelings of this sort appear to be similar to fugue states, amnesia, somnambulism, and hypnotic trance states.

When the sensory input is at a level greater than can be processed by the individual, the number of signals responded to may actually fall below the level obtained at a lower signal rate. As an extreme, a crewman who is overloaded may "freeze," unable to take any action at all. Finally, under circumstances difficult to define or predict, incoming information is distorted or ignored by the CNS, resulting in responses which are inappropriate to the situation. The conditions most commonly responsible are anxiety, fatigue, and disorders of attention which have a psychiatric basis.

Isolation and sensory deprivation effects are probably part of this same behavioral continuum. It is clear that the effects obtained under conditions of sensory deprivation, in particular, involve several other factors, including fatigue, monotony, and boredom. There is also a tie between sensory deprivation and isolation. The essential nature of isolation is the separation of an individual from objects or stimulus sources in his environment. Beyond this, if an individual is shut off from sources of information and stimulation, sensory deprivation effects can occur.

When the results of isolation and sensory deprivation studies are combined with additional information gained from the effects of other unusual environments, such as those which produce the break-off phenomenon the cataract psychosis, and the respirator psychosis, a clear picture emerges. In unusual environments, there are emotional responses which may occur in normal people. These are more commonplace than is usually recognized, but are usually of little import to the crewman's performance. These emotional responses can range from minor perceptual aberrations and other minor affective changes to gross misperceptions which may well alter crew functioning. Physical or environmental stresses may be involved in these situations, making the effects more acute. The effects are usually transient, and recovery is rapid when appropriate levels of stimulation are reestablished. While these effects have been reported often enough to demonstrate that they represent real alterations in overall levels of awareness, they occur relatively infrequently and should not be regarded as major problems.

Maintenance of Skill

We might wonder how, in the face of all physiologic and psychologic stresses infringing on mission crew, we can help each man maintain an acceptable level of performance. In addition to effective feeding and rest facilities, the following six procedures should be followed:

(a) Simplify tasks as much as possible.

(b) Reduce or remove all over-load conditions.

(c) Increase the flow of stimulation and feedback from the system back to the crewman on tasks with low arousal value.

(d) Over-train on subroutines in the complex tasks.

(e) Train exhaustively on emergency procedures.

(f) Use optimum work/rest schedules.

In brief, it is necessary to engineer the job to both reduce over-load and augment low-load conditions and then to train as frequently and intensively as possible.

PART VII

Operational Applications and Conclusions

Changes in alertness are of immediate significance to the safety and success of flying operations. For example, decreased alertness played an important role in each of these actual aircraft accidents or incidents:

> A transport crew is alerted for a long over-water mission in the early hours of the morning. After two days with little sleep, the crew nearly runs the plane off a taxiway and the balance of the mission is cancelled.
>
> A flighter-bomber squadron is deployed across eleven time zones to a new combat theater. Thirty-six hours later, at a time comparable to home base midnight, a plane is damaged in an inflight incident attributed to pilot error.
>
> A klaxon sounds at a strategic bomber alert facility. The crewmen, awakened from a sound sleep, rush to their plane and accidentally taxi it onto another aircraft killing one person.

This monograph has discussed numerous factors which may affect the biological state of alertness. Many of the basic laboratory or animal data are not directly applicable to present operational situations, but rather provide the foundation upon which current hypotheses and future research will be based. Clearly, neurophysiologic states and mechanisms play a central role--to a degree more evident in alertness than any other behavioral state or entity. Human research with visual evoked potentials provides a model for explaining distraction in the cockpit or decreased detection with time during radar vigilance. The relation of evoked response to general arousal and specific attention suggests operational remedies to vigilance problems. Either novel stimuli or adequate rest intervals will overcome the effects of habituation.

The endocrine system and particularly epinephrine also play a major role in alertness. By acting upon neurophysiologic mechanisms, they produce variations in attention which can be facilitating or degrading. Low levels of demand (or understimulation) have no effect upon endocrine excretion and result in a low state of alertness. In contrast, higher levels of demand activate the adrenal gland and cause increased concentration of circulating epinephrine while at the same time activating the neurophysiologic mechanisms resulting in a high state of alertness. In the case of excessive demand, circulating epinephrine reaches its highest levels, but performance actually worsens. Endocrine-metabolic changes such as these have been observed in a variety of military flying and air traffic control situations. When measured in personnel performing tasks requiring prolonged alertness, attention or readiness, they provide an operationally useful index of the physiologic stress involved.

Nutrition has been presented here as a substrate to alertness-a chronic factor rather than an acute one. It is of particular interest from an operational point of view because aircrewmen, especially those involved in missions of more than 5 or 6 hours, are notorious violators of good nutritional practices, for a variety of reasons. Pilots should be made aware of the diminished visual and psychomotor function which may result from missed meals. They should know the advantages of carrying a carbohydrate source for quick energy, of avoiding crash dieting and of adequate rehydration after long or hot missions. Chronic factors such as nutrition and age have received relatively little attention in aerospace medical research, but deserve more.

The relationship between demand placed on a crewman and his level of alertness is described by an inverted U. Within the framework of this model, the numerous environmental factors discussed in the monograph may be viewed as load augmenters. The external stressor, acting at low levels may actually increase alertness and facilitate performance, perhaps by stimulating increased neurophysiologic/endocrine activity. At high levels, environmental factors add to the demand at the peak of the inverted U and therefore, facilitate the degradation of alertness. In operational settings, temperature, humidity, pressure, noise, vibration, acceleration and specific task requirements all function in this manner. Other factors such as toxic gases, hypoxia and radiation produce only diminished attention. As a general principal, all environmental extremes decrease alertness and are to be avoided by aircrewmen if at all possible. Individual variability in resistance, adaptability and motivation confound this simple rule by precluding any universal definition of exactly what constitutes an environmental extreme. The importance of careful selection, training, acclimatization and physical conditioning for maintaining aircrew readiness is reconfirmed.

The basic internal mechanisms and fundamental external influences discussed in the early portions of the monograph find logical application in the concluding section on performance and fatigue. Alertness is a major component of performance. It is difficult in many instances to differentiate the two, particularly when discussing fatigue, since most fatigue effects include reduced alertness. It is doubtful that a clear separation can be made or is needed since many fatigue remedies or preventive measures apply equally well to alertness. Consequently, the concluding recommendations on maintenance of performance in the face of acute, chronic or cumulative fatigue will also prove useful to commanders who face problems of alertness. Greater attention to known factors such as diurnal variation, sudden awakening and work/rest schedules could have prevented each of the aircraft accidents described at the beginning of this section.

Alertness is a biological state, behavioral in its most obvious manifestations and clearly important for survival in the flying environment. This monograph has attempted to identify the factors and mechanisms which underlie alertness. Such knowledge will promote understanding and eventually prediction of operational conditions that diminish vigilance and attention. Most importantly for the safety and success of our aircrews, from this knowledge emerges the means to maintain high levels of readiness.

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